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ENCYCLOPÆDIA

OF

CIVIL ENGINEERING,

HISTORICAL, THEORETICAL, AND PRACTICAL.

BY

EDWARD CRESY,

Architect and Civil Engineer.

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ILLUSTRATED BY

UPWARDS OF THREE THOUSAND ENGRAVINGS ON WOOD,
BY R. BRANSTON.

R. d. 2

IN TWO VOLUMES.

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PREFACE.

CIVIL ENGINEERING must almost necessarily have been coeval with the world's existence, and that its practical usefulness was fully appreciated by the ancients seems to be shadowed forth in one of their earliest fables; for when the waters which covered Thessaly were to be drained, the land rendered serviceable for agriculture, and the air freed from miasma and pestilential vapours, no mortal could be found competent to perform the task, and Hercules was implored to cut off the Hydra's head, or to dam up the watercourses which were the cause of the inundation: but vain were the several first attempts of the hero to destroy the enemy; two heads appeared for every one removed; and until the method of searing up the wound was discovered, he failed in accomplishing his purpose.

The Phœnicians, Egyptians, Greeks, and Romans, gave active employment to the Civil Engineer, in draining marshes, mining, constructing sewers, bridges, aqueducts, baths, amphitheatres, roads, canals, moles, harbours, lighthouses, &c. &c., the remains of which are not only traceable, but sufficient to justify our conviction that they were executed by a class of men thoroughly acquainted with the principles of geometry, and many branches of natural philosophy.

After the destruction of the Roman Empire, all engineering works were under the direction and superintendence of the Freemasons, Brothers of the Bridge, and other fraternities; but Civil Engineering can scarcely be said to have taken its place among the sciences until the desire to recover the submerged lands in Italy called into action the powers of those philosophers and mathematicians of the seventeenth century, whose writings laid the foundation of our knowledge of hydrodynamics: hydraulic architecture as practised in Italy soon spreading over the greater part of Europe. Galileo, Torricelli, Castelli, Gulielmini, Poleni, Manfredi, Zendrini and others, became distinguished for the laws they propounded upon the active properties of water. The torch of theory was then kindled by practice, and again gave back to the artificer and mechanic a light more brilliant than they had before enjoyed.

In France, Belidor about the same period collected all the information that might be useful to the Civil Engineer, which he published under the title of "Architecture Hydraulique;" a work deservedly esteemed, and considered as the primer of the modern school of engineering in that country.

In England, the profession of the Civil Engineer was scarcely known until the middle of the last century, when the important discovery of the application of steam by James Watt, and its rapid development, called into existence a new class of mechanics, who gave a fresh impetus to manufactures by the improvement of all kinds of machinery. The vast commercial enterprise which attended this movement, and its great and growing success, have necessarily led to the enlargement of our harbours, and the improvement of our inland navigation; the progress, too, of an enlightened civilisation in its regard for the sanatory condition of the empire, requires that our towns and cities shall be amply supplied with water, lighted, drained, &c.; while innumerable other causes are almost daily arising to call for the reconstruction of our quays, bridges, and every other work executed before this great and general movement in civilisation was made. During the last half century hundreds of millions sterling have been devoted to these important objects, and, great as the amount may appear, it is infinitely less than what will be expended upon railroads alone if the country remains at peace, and its prosperity unimpaired. Under these circumstances it will at once be seen of what importance it is that the Civil Engineer should be qualified to discharge his duty in the great career that

lies before him. To enable him to perform his multifarious functions with honour to himself and satisfaction to his country is the great object of this Encyclopædia: and, without further preface, we shall proceed to lay before the reader an outline of its contents, and the plan we have adopted in its compilation.

The first portion of the work is devoted to the history of the past; for it has been thought that a knowledge of the manner in which others have accomplished works similar to those we are called upon to execute at once facilitates our labour and inspires us with confidence in what we are about to undertake.

In treating of *Geology*, *Mineralogy*, and *Chemistry*, the only aim has been to point out the nature of these subjects, and give a general idea of the properties of the materials which form the earth's crust, with an account of their composition, as far as might be generally serviceable to those who employ them in the arts of construction, or operate upon them mechanically.

Geometry, as the very foundation of the acquirements of the Civil Engineer,—embracing, as it does, levelling, surveying, the mensuration of planes and solids; trigonometry in all its practical applications; drawing, perspective, mapping, laying down charts, and all the preliminary steps to great undertakings, as well as their execution,—should be made the first study of all who are desirous of becoming acquainted with the other sciences; for without it, in fact, no portion of them can be rightly comprehended.

Mechanics are also a most important subject. The ancients, indeed, knew the principles of the inclined plane, the wedge, the screw, the lever, and the pulley, and by their application were enabled to move the vast weights accounts of which are transmitted to us; but the improvements made in machinery in modern times have undoubtedly enabled us to execute works of vast magnitude with a great saving of manual labour. From experiments upon the strength and properties of the metals, and the application of geometry to mechanics, we can construct machines, which from their variety of movement, and the useful purposes to which they are applied, are inventions and novelties which belong to the present age. The tools and engines employed by the Civil Engineer are instances of the advancement in this branch of physics.

Hydrostatics, with the theory of the motion of fluids, and the various hydraulic machines that have been invented, facilitate the operations of the Engineer in raising water, directing its course usefully and efficiently, whether for sanatory, domestic, or agricultural purposes; and without an almost complete command over this element, he can scarcely be considered worthy of his high vocation.

The nature of the Atmosphere, and its properties as a moving power, has greatly occupied the attention of mechanics in all ages, and its services cannot be too highly appreciated. For the construction of windmills and similar contrivances, numerous experiments have been made, replete with benefit to the millwright.

Warming and Lighting are daily becoming matters of public attention, and must therefore occupy the consideration of every man of science; but the Civil Engineer must beware of fanciful theories: whatever may be his system, it must be based on a thorough knowledge of the elements which he is to direct, and he must never lose sight of the requisite balance to be maintained between the heat generated and the ventilation. Lighting our coasts has occupied the attention of such philosophers as Professor Faraday, whose interesting discoveries have greatly improved our light-houses, and elevated this subject into an important science.

Gas Lighting has its engineers, who have improved the methods of distilling coal, and laid down principles to direct the proportions of every part of the establishment where such works are conducted.

Steam, considered as a moving power, is the most extraordinary discovery of this or any other age. By its application manual and horse labour have been greatly economised; machinery of every kind is set in motion; and millions of human beings are transported in a short space of time from one end of the empire to the other. This branch of our subject, it is unnecessary to add, particularly deserves our study.

Carpentry, which embraces the construction of *timber roofs*, *bridges*, *centres*, *scaffolding*, *&c.*, with a thorough knowledge of the use and properties of timber, has been treated at considerable length; though not more so than the importance of the subject demands. Although iron has in this country superseded the employment of timber in many instances, there are occasions in which the carpenter's art

cannot be dispensed with; moreover, the principles embraced by it are also those practised by other artificers, and deserve to be understood, if on that account alone.

Masonry is another branch of artificer's work necessary to be thoroughly understood by the Civil Engineer. The construction of every variety of arch and dome occupies several pages: while the mathematical calculations upon the strength of stone, the effects of thrust and pressure, are dilated upon in several parts of the work. The examination of the qualities of the various stones used in construction, together with an analysis of them, has been also fully detailed from parliamentary and other documents that may be relied upon. As a science the mason's art has not in this country been made sufficiently prominent, nor excited sufficient interest to call forth a treatise on the subject; but a volume would be necessary to exhibit the varieties of construction, the skill displayed in overcoming the many difficulties that arise, and the gradual progress of this highly important branch of the profession.

Stone Bridges, and the principles upon which they are constructed, should be thoroughly studied by the Hydraulic Engineer, as they embrace all the knowledge required for the formation of docks, harbours, piers, jetties, quays, &c. which are among the most triumphant efforts of the engineer. Of the machinery invented to aid these works, and for which we are indebted to the bridge-builders of the last century, ample accounts have been given in that portion of the work devoted to machinery. The stone bridges over the Thames at London are highly deserving of attention; they may be considered as the result of great study, and the best examples of the application of science to such structures.

Canals, though now superseded by Railways, ought not on that account to be entirely neglected: for should steam navigation be still further improved, it is not improbable that the data which have occasioned their disuse may prove more favourable for their future construction, and hence the principles which belong to their formation should be thoroughly understood by the civil engineer, as there are many localities where canals would have a decided preference over railways.

Draining and Embanking have from a very early period occupied the attention of the government as well as individuals. To confine rivers within their banks, and draw off the surplus waters from the surface of the land, are not only benefits conferred on agriculture, but on its cultivators, by rendering the atmosphere more salubrious and agreeable. Towns and cities also require attention to their sewerage, and the cleansing of the streets; and several local acts of parliament have been passed to enable these objects to be carried into effect; but one grand comprehensive view is still wanting for this to be thoroughly accomplished, and it will never be attained until the united efforts of a number of engineers, well-instructed in Geology, shall suggest for every district the best means of attaining it.

Railroads have given an extraordinary impetus to the profession; but it is time that the principles of their construction should be better comprehended: the public, at whose expense these highly important works have been executed, having hitherto generally preferred the *mechanic* to the *artificer*, as the director of the chief lines that have been completed. The construction of a railroad requires a great combination of talent before it can be brought to perfection. The selection of the country through which it is to pass, the building of bridges and viaducts, laying down rails, &c., are even more important considerations than the locomotive engine, which draws vast loads along the line. We have already had numerous failures, where the arts of construction have been employed, and it is to be desired that the engineers entrusted with the expenditure of such vast sums as are embarked in these speculations would qualify themselves, at once to comprehend these arts, and to practise them beneficially.

The Principles of Proportion which regulate the quantity of material to be employed in the arts of construction should be diligently studied both by the Architect and the Civil Engineer. To this subject the author has devoted the most careful consideration, having measured a vast number of buildings of all ages, for the purpose of forming an opinion upon the difference of character expressed in the Doric, Ionic, Byzantine, and Mediæval styles. For economic purposes this enquiry is worthy of great attention, it being apparent that if an entire building or a portion in the Byzantine style be cubed, one part out of twelve only is devoted to material; in St. George's Chapel, Windsor, two parts; in the Chapter-House at Wells four;

in the Ionic porticoes six; in the Doric eight; a variation between a twelfth, a sixth, a third, a half, and two thirds of the entire cube being employed for supports, and the remainder for space.

One of the great features of the age is the division of labour, and as the population increases, and the influence of knowledge spreads, it seems likely to be *still* further carried out. The province of the Civil Engineer at present extends over the works performed by the artificer, miner, and mechanic; he is entrusted with the direction of all that is difficult and scientific in construction, whether upon land or water, as well as with designing the machinery necessary for these important purposes. This knowledge was formerly demanded of the *architect*, who in addition was required to be acquainted with the fine arts. *His qualifications*, according to Vitruvius, were to embrace all that could be known; and many *illustrious* names could be adduced to prove that the requirements of the great Roman architect were fulfilled to the letter.

To design an edifice that shall have "Commodity, Firmness, and Delight," or to render it both serviceable and expressive of its purpose, requires a variety of talent; and it is to be feared that the architect who confines his attention solely to that portion embraced by the fine arts will eventually lose his power: for without studying the principles of construction, he cannot give character to his design, and is not qualified to be entrusted with the execution of a work. On the other hand, should the Civil Engineer be required to act as architect, he must pursue the course adopted by Sir Christopher Wren,—set out upon his travels, and examine and study those buildings which have received the approbation of the most competent judges; and he will find that Egyptian, Grecian, Roman, and Mediæval architecture, have each its peculiar principles and character of expression. Equal application is required for a perfect initiation into the knowledge of architecture as a fine art as for that of the science of construction. St. Paul's, London, which is a masterpiece of construction, gives but too strong evidence that the genius of the mathematician had not profited sufficiently from his journey in search of what was consistent and perfect in architecture; he did not even advance so far in that study as his predecessor Inigo Jones. We admire this splendid edifice, not for its architecture, but for the principles developed in its construction. Those who pass judgment on a design should be in possession of all the elements necessary for such a task. They should be acquainted with construction generally and in detail, and should understand the proper relative proportions of every part of the edifice. The public are enabled to pronounce the Menai Bridge to be both beautiful and useful: but before the architect can decide that it is a perfect work of its kind, he must be satisfied, not only that every tie rod and strut is rightly proportioned, but that all of them in their respective characters express their functions, producing a whole combining security, solidity, and utility.

It is impossible to dismiss this portion of our subject without expressing feelings of the most painful regret at the position which Architecture now appears to hold in this country. In France, Germany, and throughout Europe, it occupies its rightful place, as the chief and most important of the arts of design: there the architect is prepared for the exercise of his profession by a long course of study, tested by strict examinations in elementary mathematics and the sciences of construction, while all the student's talents and energies are called forth by the spirit of emulation produced by contests for medals and academic honours. Foreign governments powerfully contribute to the encouragement of successful merit by bestowing thereon their patronage and protection, by conferring civil orders and decorations, and by endowing academies and professorships, which enable the man of science to devote his leisure to the cultivation and advancement of his art.

The Engineers, estimating at its true value the power acquired by combination, have wisely united "for the general advancement of mechanical science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer." They have defined the nature and objects of their Institution; they encourage the student to cultivate the sciences ancillary to his profession, and, by the distribution of medals and prizes for the most able memoirs, incite him to the study and description of engineering works at home and abroad. Nor has the means of furnishing the aspirant with opportunities for acquiring theoretical knowledge been neglected: the College of Civil Engineers, the engineering classes at King's and University Colleges, and at the University of

Durham, communicate much valuable information, which would have been inaccessible in the office or workshop. For the architect no such means are provided, nor has the Institute defined the art in a manner to make the public feel its value or necessity. Let the architects follow the wise example of the engineer, and they will have done much to acquire for their art the respect and encouragement of their countrymen, and to place it in the elevated position which elsewhere it so deservedly occupies.

For the information contained in this Encyclopædia, the author is indebted to several eminent writers, and to numerous tours which he made for the express purpose of observing the engineering works both of this country and on the continent. The practical observations are the result of thirty years' employment in his profession; but he has freely borrowed the opinions suitable to his undertaking from every trustworthy source to which he has had access, and more especially from the following foreign authors, a more extended perusal of which he earnestly recommends to every student.

Gauthey, "Traité de la Construction des Ponts, &c.;" M. Belidor, "Architecture Hydraulique;" M. Rondelet, "L'Art de Bâtir;" M. Bruyere, "Etudes relatives à l'Art des Constructions;" M. Perronet's "Description des Ponts, &c.;" M. Prony's "Nouveau Architecture Hydraulique," and "Description Hydrographique et Historique des Marais Pontins;" M. Boistard's "Observations faites sur différens Travaux;" M. Berard's "Statique des Voutes;" M. Hachette's "Traité des Machines;" MM. Lanz et Bétancourt, "Sur la Composition des Machines;" M. Borgnis, "Traité complet de Mécanique appliquée aux Arts;" M. Mallet, "Géométrie pratique, &c. &c;" the several Essays comprised in the "Raccolta d'Autori Italiani, che trattano del Moto dell' Acque," whose names are frequently introduced where this subject is discussed; Alberti, "l'Architectura;" and above all, the "Opera M. Vitruvii Pollionis," edited by Poleni and Stratico, 4 volumes. He has also to acknowledge assistance received from his eldest son, Edward Cresy, whom it has been his wish to qualify for the exercise of the important duties both of *architect and civil engineer*, and who, whilst studying his profession, executed nearly the whole of the drawings, so ably cut on wood by Mr. R. Branston, of St. Andrew's Hill Doctors' Commons, to whom he offers his best thanks for his care and attention during the progress of the work.

To conclude: the author's great desire has been to embody in one volume all the leading principles and multifarious details on which the science of Civil Engineering is based; and to produce a work that might at once instruct the pupil, and prove a useful guide to him in his professional career. The work, he believes, is the first on the subject which has been published in this country. The labour bestowed upon its compilation has been of no ordinary kind; and he terminates it with regret, feeling assured that one individual could not do justice to a subject involving so many considerations of public importance. Should he, however, be so fortunate as to awaken in the mind of the young engineer a love for his profession *per se*, and a sense of the honourable position in which he may place himself by careful study and an undeviating course of integrity, he will not think that he has laboured in vain.

E. CRESY.

South Darenth, near Dartford, Kent.
January, 1847.

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ENCYCLOPÆDIA

OF

CIVIL ENGINEERING.

BOOK I.

HISTORY OF ENGINEERING.

CHAPTER I.

PHŒNICIAN ENGINEERING.

As commerce and the art of war equally require the assistance of the engineer, his employment may be dated from the time when history notices the one, or relates the success which attended the other. War, in the early ages of the world, being considered more honourable than the arts of peace, traffic and the handicraft trades would be but little esteemed; and so few good workmen were then to be met with, that we read of such a hero as Ulysses being obliged to construct his own boat, as well as to decorate the furniture his rude palace contained. As the knowledge of navigation improved, and traffic became more general along the shores of the Mediterranean Sea, the inhabitants found that the high precipitous cliffs, broken into headlands, and the numerous indented islands, by the assistance of art might be made to afford better protection to their vessels against the sudden storms to which that sea is subject. To the architect, whose studies comprised all the sciences which had been developed by society, and united in his employment what was then known of construction, the lifting of heavy weights, and the arrangement of machinery, was confided the adaptation and improvement of nature's works; their defence from aggression of every kind; the formation of the city, the roads, the supply of water, and all that was deemed necessary or essential for the wants or the pleasures of the inhabitants.

To the Phœnicians, who so long enjoyed the dominion of the Mediterranean Sea, we must give the credit of first encouraging the art of civil engineering: they were among the earliest descendants of Noah that settled on the coasts, and who made navigation subservient to commerce. These people, named Canaanites, which, in the Eastern language, signifies merchants, first inhabited a city called Sidon, in consequence of its being built by the eldest son of Canaan, whose name it bore. The country around not being fruitful, the inhabitants were obliged to turn their attention to manufactures and commerce, and use every means to induce other nations to trade with them, and take off their surplus productions in exchange for the necessaries of life.

In the days of the patriarch Abraham the settlers here had become so powerful a people, that when Jacob blesses his children, he tells Zebulon "that he shall dwell at the haven of the sea, and he shall be for a haven of ships, and his border shall be unto Sidon."

The Phœnicians lost the greater part of Canaan which they held, in the time of Joshua, when the land as far as Sidon was given to the tribe of Asher. The inhabitants were not, however, destroyed, but suffered to extend their commerce, and to send out colonies to the shores of Africa and Europe. Cyprus, Rhodes, Greece, Sicily, Sardinia, Gaul, and Spain, received settlers from the Sidonians, who taught the native inhabitants the first rudiments of science.

Twelve hundred and fifty years before Christ we find these enterprising merchants passing through the Straits of Gibraltar, and founding the port of Cadiz, where they laid up in extensive warehouses the produce they freighted from all parts of the then known world. Gold, silver, copper, lead, tin, and iron, they supplied in abundance, and these metals they obtained either by exchange with the natives, or by working the mines which they discovered.

Sanchoniatho, who was supposed to have been a contemporary of Joshua, has left us many traditions of the Phœnicians.

Sidon is at present a town of considerable importance, known as Saide or Seide. This ancient port is nearly choked up with sand; the houses which rise from it, and contain upwards of 15,000 inhabitants, are built along the shore, and impart, as the traveller

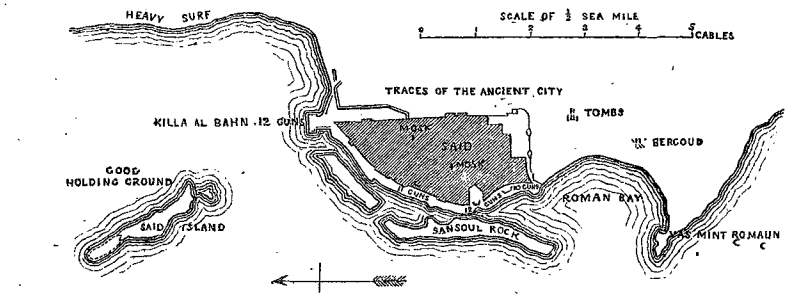


Fig. 1. SIDON.

approaches, the idea of a place of some extent. Considerable employment is still given to the spinners of cotton and manufacturers of leather, and at a short distance from the shore is the island of Said, once connected by a mole with the main land, and forming a second well-sheltered harbour. The Roman bay is commanded by a modern battery, and behind this Turkish fortress are traces of the ancient city; and the remains of several tombs. Homer, in the 15th book of his Odyssey, mentions this city; and in describing the arrival of one of its ships, tells us how it was freighted, and that it contained toys and fancies of every sort. The same poet often alludes to the works of art, the mantles of various hue, the dyes, the silver goblets, the beads of amber rivetted on gold, and other articles of luxury that were sent from Sidon; and that the fair Sidonians were highly accomplished in embroidery and other ornamental works.

Sidon was rendered important from the mercantile disposition of its inhabitants, who were also skilled in producing all kinds of manufactures then in demand; the mountains of Libanus in their rear afforded them abundance of timber for ship-building, with which they constructed vessels that carried their surplus produce to the most distant lands. Had Faccardine, the emir of the Druses, who dreaded the constant visits of the Turkish fleet, not demolished the ancient mole, we might have had it in our power to describe a structure of the golden age, or of the time when giants are said to have given their aid: for vast indeed in dimension are many of the stones that lie scattered along the coast, and which once formed the mole that shut in their harbours. Some of these stones are reported to be long enough to have extended through the whole thickness of the mole. At present a ledge of rock affords the only shelter to vessels which frequent this port; this is a short distance from the coast, and stretches itself in front of the citadel towards the north. This ancient port for a long period enjoyed the sovereignty of the entire Mediterranean; and as the surrounding country was barren, the inhabitants could not have subsisted without commerce, which brought in its train the arts. Some of their early bronze and silver medals bear proof how highly they were advanced, and history attests the success which attended their navigation. Homer, according to Strabo, speaks only of Sidon, when he alludes to the inhabitants of Phœnicia.

Tyre, or *Sor*, called "the daughter of Sidon," stood also on the sea, at a distance of about 200 stadia southward. We must be careful not to confound the three different cities which had this name. The first in order of time was old Tyre, on the continent; then Tyre on the island; and Tyre on the peninsula, after the island was joined to the main land. It had two harbours; one lying north, and the other south, or towards Egypt, which were formed by the isthmus; the latter was a close harbour, and the opening through which ships entered was fortified by drawing a chain across it. An artificial mole still defends this bay; and probably the rocks on the other side were once built upon, thoroughly to enclose it. Northward, at the head of the island, stretches out, from a ruined light-house, another mole, which protected the northern harbour. Since the uniting of the island a gully has been formed, as if the sea had again broken through, and once more separated it from the continent. Tyre on the island, and old Tyre on the main land, for a long time constituted one city: according to Pliny, the island was 700 paces from the continent; but, according to Strabo, 30 stadia, or nearly three of our miles. The same author states that the walls which encompassed it were 150 feet in height, proportionally broad, and built of large and massive blocks of stone, embedded in mortar. Modern travellers place the island at about a third of a mile distant from the

shore. Old Tyre was first destroyed by Nebuchadnezzar, after a siege of thirteen years, the inhabitants having removed all their treasures to the island. The conqueror was

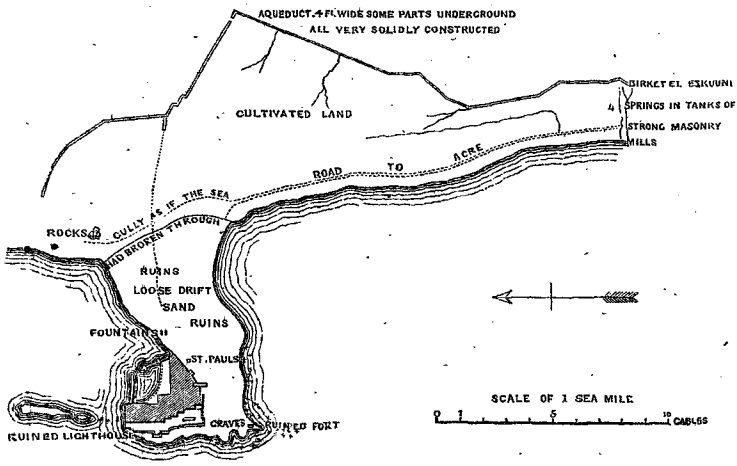


Fig. 2. TYRE.

therefore obliged to rest satisfied with destroying the town on the main land, after which he set out towards Egypt. The Tyrians were then compelled to submit to the rule of the Babylonians; and, for seventy years, were governed by kings of their nomination. The Persians then restored to them their independence, whom they assisted when Xerxes carried on his wars against the Greeks: and Herodotus informs us that the kings of both Tyre and Sidon formed part of the Persian monarch's council of war.

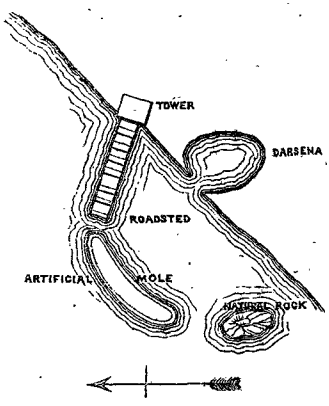


Fig. 3. TYRE.

About 332 years before Christ these cities were destroyed by Alexander, who, in his march towards Egypt, compelled all the cities of Phœnicia to submit to him.

Tyre obstinately refused him entrance, when he immediately commenced the memorable siege, which ended by his taking the city by force of arms: the height of the walls, the strength of the navy, and the abundance of all things for defence, made it a difficult and almost hopeless attempt.

He began, says Diodorus, by demolishing old Tyre, and employed his army to carry away the stones, and raise a mole, 200 feet in breadth, which was speedily advanced. Whilst this was doing, the Tyrians determined to send their wives, children, and old men to Carthage, and keep their young men to defend their walls; but this was not carried into execution: the walls were covered with new-invented engines, and especially on that side where the mole was in progress.

When the mole was carried within a short distance, or the cast of a dart, a large whale was thrown upon it, much to the alarm of all parties: the citizens being struck with the increase of the mole, sallied out in small boats, accompanied by slingers and archers armed with engines of all kinds for the discharge of arrows and darts.

A violent storm of wind arose, and destroyed a portion of the work, and broke through the mole. This was speedily repaired, by causing large trees, cut down in the mountains, to be thrown in, with their branches entire; on which was heaped a quantity of earth, to render it strong enough to resist the violence of the sea. When the mole was complete, and within a short distance of the walls, Alexander commenced battering them down, discharging at the same time darts and arrows out of engines at the besieged. The Tyrians, to guard against these missiles, had contrived wheels with long spokes of

their battlements, which, turning constantly round, shivered all the darts that came in contact with them to atoms; and they checked the violence of the stones thrown by the balistæ, by woolpacks placed in proper situations to receive them.

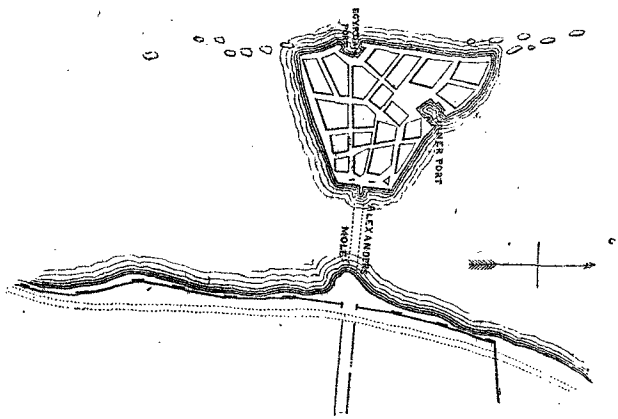


Fig. 4. TYRE.

The Tyrians did not relax in their exertions. They built within their outer wall another, ten cubits broad, and five cubits distant from the former, and filled in the space between with earth and stones. Alexander then constructed a battery, by joining many of his ships together, and then placing the rams against a portion of the wall, beat down 100 feet of it, when he attempted to pass through the breach, but was repulsed by the Tyrians, who during the night again rebuilt the wall which had been battered down. The Macedonians then approached with towers as high as the battlements of the Tyrian walls, and, casting out planks, formed a bridge. Here they were again repulsed by the Tyrians, who had contrived long tridents, or three-forked hooks, to grapple and wound those placed on the top of the towers; these grapples, attached to ropes, they flung over the shields of the assailants, and tore them out of their hands. Nets were thrown over those who attempted to pass over the bridges formed of planks, and they became so entangled, that many of them tumbled headlong to the ground. They also filled their iron and brazen shields with sand, and after they had made it scorching hot by placing them over fires, it was by means of a machine cast upon the besiegers, and getting between their breastplates and coats of mail, burnt their flesh, and many died in consequence. The Tyrians sent off fire darts, heavy stones, and all kinds of missiles, and with long poles, armed with sharp knives and hooks, they cut the cords of the battering rams in pieces: they also discharged out of their machines masses of red-hot iron; they plucked men off the ramparts with iron instruments shaped at the end like a man's hand.

Alexander was undismayed, and unwearied in his exertions: he continued to batter the walls, and discharge ponderous stones out of his engines, and all sorts of missiles from his wooden towers. Marble wheels placed upon the walls, and kept constantly turned, were made to throw them off, and render them ineffectual: hides and skins were also sewn together, which, being soft and pliant, were placed in other situations for the same purpose.

At last, Alexander perceiving that the wall next the arsenal was weaker than the rest, he brought all his galleys which contained his best engines chained fast together to that place; here he cast a plank from a wooden tower with one end upon the battlements of the walls, thus forming a bridge, and alone mounted the rampart, to the astonishment of all, neither regarding the danger nor the assaults of the Tyrians: his Macedonians quickly followed: he came first in contact with the enemy, and killing some with his spear, others with his sword, and tumbling others down with the boss of his shield, he overcame his adversaries. During this time the battering rams had made another breach in the wall, and the Macedonians entering, joined the party fighting with Alexander, and by this means at last was the city taken.

The Tyrians, throughout this siege, made a most valiant defence; but instead of their bravery awakening in the breast of the conqueror an admiration for their courage, to his lasting disgrace he ordered two thousand of the chief inhabitants to be crucified, and sold thirty thousand for slaves: eight thousand of its chief soldiers perished in the combat, and the city itself he burnt to the ground.

Nearly twenty years afterwards we again find Tyre able to resist an attack made upon it by the fleets and armies of Antigonus, who, after a fifteen months' siege, captured it.

It subsequently fell under the dominion of the Roman empire; and the Latins were not finally driven from Syria until about a century after the death of Saladin. In the year 1188, Conrad of Montserrat was hailed as the prince and champion of Tyre, which was then besieged by the conqueror of Jerusalem. The Egyptian fleet was allowed to enter the ancient harbour, the chain was immediately drawn across the entrance from mole to mole, and a thousand Turks were slain. Saladin was obliged to burn all his engines, and make a disgraceful retreat to Damascus. Afterwards, Tyre was a place of rendezvous to the ships of Genoa, Pisa, and Venice, and eventually it became a part of the Turkish dominions.

The insular Tyre, destroyed by Alexander, is now "a place for the spreading of nets in the midst of the sea," as Ezekiel prophesied; the mole which the conqueror raised was washed away by a storm, and thus the peninsular state of Tyre was destroyed.

Aradus was also a city belonging to the Phœnicians; and another, called Tripoli, was built by the inhabitants of Aradus and Tyre, and hence its name.

The settlers at a very early period excelled in the sciences, and brought the arts and manufactures to great perfection. They were the inventors of astronomy, and from them the Greeks received their letters. The glass, the purple dye, and fine linen, produced here, was celebrated all over the then known world; they were skilled in the working of metals and carving of timber; and were so perfect in the arts of construction, that we hear of them, in the time of Hiram, being employed by king Solomon in the construction of his temple, more than 1000 years before our era.

As merchants, they had the commerce of the world; as navigators, they were the most experienced; and the greatest discoverers as well as planters of colonies; and for many ages they had no competitors.

They carried on considerable trade with Syria; and, having convenient harbours, and excellent timber furnished them, they built great numbers of ships.

Carthage, according to Velleius, was founded 65 years before Rome; while many writers imagine that it was built 130 years before the imperial city, by Dido, the sister of Pygmalion, king of Tyre, and wife of Sichæus; and the Tyrians she carried with her, to colonise this new settlement, were among the most skilful in the arts of the then known world: the form of government she introduced was by Aristotle said to be the most perfect in existence.

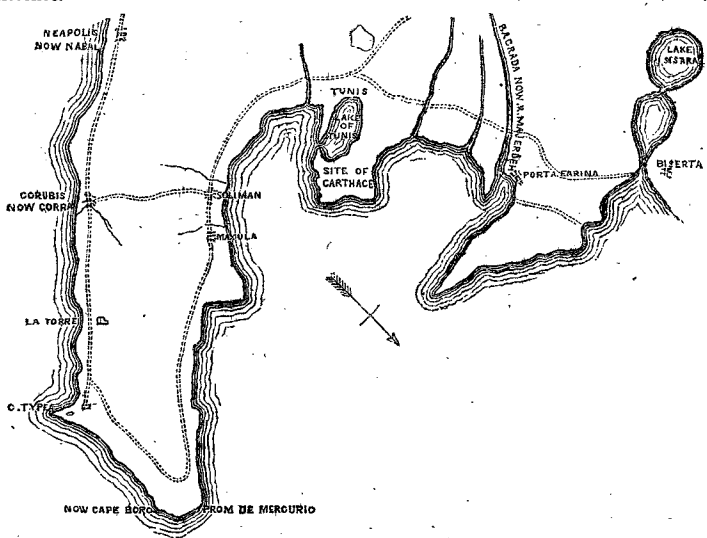


Fig. 5. CARTHAGE.

Carthage was situated at the extremity of a gulf, upon a peninsula 360 stadia or 45 miles in circumference; and the isthmus which united this peninsula to the continent of Africa, was 25 stadia or more than 3 miles in breadth. On the west projected a long slip of land, half a stadium in breadth, which separated the sea from a lake, which was strongly protected by rocks on both sides.

In the middle of the city was the Acropolis, called Byrsa, where was a temple to Æsculapius. On the south side of the city was a triple wall, 30 cubits in height, and at every 480

feet was placed a tower, which had its foundations laid at a depth of 30 feet, and was four stories in height, being carried up two stories higher than the walls.

There were two harbours, so disposed that they communicated with each other, although they had but one common entrance, which was 70 feet in breadth, secured by chains. One was devoted to merchant ships, and the inner port, as well as the island called Cothon, in the midst of it, which was surrounded by spacious quays, was made secure for the reception of 220 ships of war. Magazines, storehouses, and all the requisites of an extensive arsenal, were constructed around it; and the entrances to the harbours were decorated with marble porticoes, so that the whole might be said to be encompassed by two magnificent galleries. Upon the island was the residence of the governor, facing the mouth of the harbour, so that he could see all that was passing both within and without the port. When the merchant ships entered, it was not possible for them to view what the inner port contained, as it was shut in by a double wall, and each port had its particular gate.

The city had three divisions: Byrsa, Megara, and Cothon. Byrsa was three miles in circumference, and stood nearly in the centre of Carthage, surrounded by Megara, which contained the houses of the citizens: these, at the time of the third Punic war, were numbered at seven hundred thousand. Livy gives twenty-three miles for the measure of its circumference, and Suidas affirms it was the most powerful city in the world: it enjoyed the dominion of the sea for more than six hundred years, and had an extensive and lucrative commerce. The Carthaginians possessed three hundred cities in Africa, and their territory extended from the western confines of Cyrenaica to the Pillars of Hercules, a distance of upwards of fifteen hundred miles. Spain, Sicily, and all the islands of the Mediterranean also belonged to them. The Carthaginians, who disputed the empire of the world with the Romans for a hundred and eighteen years, were destroyed as a nation a hundred and forty-six years before Christ. Æmilianus, the Roman general, made two attacks, one against Byrsa, and the other against Cothon; and having become master of the wall which surrounded the port, threw a considerable force into the great square of the city; soon after which, Asdrubal abandoned the Carthaginian troops, and went over to the Romans: his wife could not survive such perfidy, and committed herself, children, and followers to the flames which then enveloped the citadel and temple. Soon after, the victorious Romans demolished Carthage, as well as the cities dependent upon it, and the territory was declared a Roman province.

The enormous wealth that had been amassed by this commercial people is stated by Pliny at upwards of four millions four hundred and seventy thousand pounds weight of silver, which was carried away by Æmilianus.

Carthage is now at a considerable distance from the sea; the north-east wind and the Merjedah have closed up its ancient harbour. The place is called El Mersa; the port lies to the north and north-west of the city, and forms, with the lake of Tunis, the peninsula on which Carthage was built.

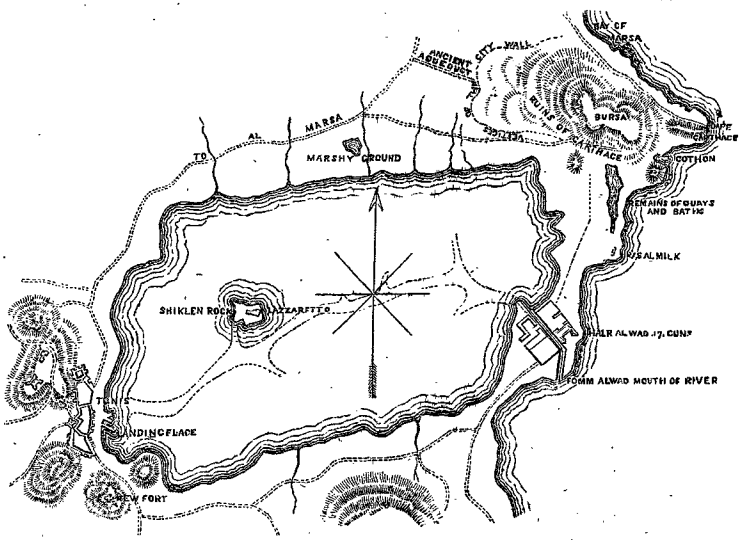


Fig. 6. CARTHAGE.

Upon the other side, Carthage has been a loser by the encroachment of the sea, a considerable tract that was land being now under water. The traces of Cothon, though scarcely a hundred yards square, may be yet seen. Along the shore the openings of the common sewers remain; and also, at a short distance, the great reservoirs and aqueduct, near the western wall of the city. There are more than twenty of these water-cisterns, each a hundred feet in length, and thirty in breadth, and the water was conveyed to them through earthen pipes, still visible.

CHAP. II.

EGYPTIAN ENGINEERING.

Egypt boasts of as great antiquity as any other nation of the earth. It may be called the cradle in which the sciences were first nursed, and the source from whence the Greeks, in after times, drew their knowledge; and we must admit that a great portion of our modern skill, particularly in engineering, had its rise on the banks of the Nile. This country is bounded on the east by the Isthmus of Suez and the Red Sea, on the south by Nubia, on the west by Libya, and on the north by the Mediterranean; its length from north to south is about 500 miles, its greatest breadth 250, while at some parts it is very much less. It lies between the twenty-first and thirty-first degrees of north latitude.

The waters of the Nile which pass through it, have their rise in the Gebel Alcomri, and the course of this noble river measures upwards of 2000 miles, whilst its breadth seldom exceeds the third of a mile, or its depth twelve feet.

The Delta, which is a luxuriant district, is composed of pure black unctuous mould, and for the purpose of vegetation needs no manure; it is entirely alluvial, and formed by deposition of matter brought down by the waters of the Nile. This delta is not wholly covered by the inundation of the Nile, though throughout the habitations are built upon mounds raised considerably above the level of the standing water; and it is from the formation of these earthworks, and the cutting of canals for the irrigation of the land, that the rudiments of civil engineering may have had their origin.

The Nile was perhaps one of the earliest rivers devoted to the purpose of inland navigation; and, according to Gibbon, "the servitude of rivers is the noblest and most important victory which man has obtained over the licentiousness of nature;" and, without doubt, agriculture would first derive advantage from their subjection, occasioning them to be confined within certain limits by artificial embankments. The earliest cities were founded on the banks of rivers; and the first operation performed by their inhabitants, both for salubrity and convenience, would be the cutting of dikes, for the purposes of drainage and occasional irrigation. In Egypt, before the time of Menes (*Herodotus*, lib. ii. c. 99.), who lived 2320 years before the Christian era, the Nile continued its course along the sandy mountain on the side of Libya; but this king, by constructing a bank at the distance of a hundred stadia from Memphis towards the south, diverted the course of the river, and led it, by means of a new canal, through the middle of the valley: and it seems that in the days of the historian, during the time of the Persian dominion, this artificial canal was annually repaired and maintained. At the period referred to, the whole of Egypt, with the exception of Thebes, was an extensive marsh; and to Menes is attributed the forming of watercourses, by cutting and embanking, for carrying off the superfluous waters. Herodotus (lib. ii. cap. 137.) further states, that when Sabacus, the king of Ethiopia, governed Egypt, he made it a rule not to punish any crime with death; but, according to the magnitude of the offence, he condemned the criminal to raise the ground near the place to which he belonged, by which means the situation of the different cities became more and more elevated: they were somewhat raised under the reign of Sesostris, about 1659 years B. C., by the digging of the canals, but they became still more so, under the reign of the Ethiopian. To prevent the water of the Nile from continually overflowing the country, and to maintain a supply for the purposes of irrigation, the lake Mœris was formed, which, according to Herodotus, was 450 miles in circumference (lib. ii. cap. 149.), and was terminated about 1385 years B. C. By some authors it is said to have been in places 300 feet deep; for six months in the year the Nile supplied this lake with water, by means of a canal, which during the remaining portion of the year returned to the river. This canal, a stupendous effort of art, is still entire; and, according to Savary, is forty leagues in length: there were two others, with sluices at their mouths, from the lake to the river, which were alternately shut and opened, as the Nile increased or decreased: thus the water, which would have been carried off to the sea, was retained for the moistening the earth after seed-time. Diodorus Siculus (lib. i. cap. 4.) states the canal to have been 80 furlongs in length, and 300 feet in breadth, and that the sluices were of such a nature that they could not be opened or shut at a less charge than 50 talents (12,916*l.* 13*s.* 4*d.*); and in all probability it was necessary to cut through the embankments to attain the object desired.

Among the other benefits conferred by Sesostris on the people of Egypt, we find that of cutting many canals and deep dikes, at right angles with the river, as far as from Memphis to the sea, for the quick conveyance of corn, other provisions, and merchandise (*Dio. Sic.* lib. i. cap. 4.), the barter of which would supply fresh luxuries to the inhabitants of this agricultural country; and thus the advantages arising from this external commerce would stimulate an ardour for further internal communication; and unquestionably the best means that could be employed by an intelligent governor to procure competence to every class of citizens, would be the facilitating the transport of provisions; and the most simple and efficacious means of attaining this desirable end, is the uniting the different provinces of an empire, by improving the navigation of rivers, and forming artificial ones, where nature seems to have denied that assistance. Doubtless, the extensive commerce which must have been carried on under the sway of this prince, gave rise to many of the canals with which Egypt was afterwards intersected; for we find from Diodorus Siculus (lib. i. cap. 4.), that he sent forth a navy of four hundred sail into the Red Sea, and was the first Egyptian that built long ships, which, it is true, were principally designed for the purposes of conquest; but the general character of Sesostris gives the idea that the internal grandeur of his country and the improvement of his people were never neglected. At a later period, about 610 years before Christ, Necos, son of Psammeticus, commenced the difficult undertaking of uniting this sea with the Mediterranean by means of a canal, which was opened about twelve miles to the north-east of the modern town of Belbays, called by the Romans, Bubastis Agria; and after a course, nearly east, of thirty-three miles, it turned to the south-south-east, and continued sixty-three miles further, to the extremity of the Arabian Gulf. This canal was wide enough for two triremes to pass abreast; and it is stated that 120,000 Egyptians perished in the prosecution of the work. Several monarchs continued it; but, according to Pliny (lib. vi. cap. 29.), it proceeded no further than the lakes called the Bitter Springs, when it was abandoned, from fear of the greater height of the waters of the Red Sea. This author states its breadth at one hundred feet, and its depth forty, and the distance from the western entrance to the Bitter Lakes thirty-seven miles. Strabo asserts that ships of the largest size could navigate it. After the time of the Ptolemies it was neglected, until the caliph Omar, in 644 A.D., re-opened it, and cut another canal, called that of the Prince of the Faithful, south of Cairo: it was used for more than 120 years, until the commerce of Alexandria was destroyed.

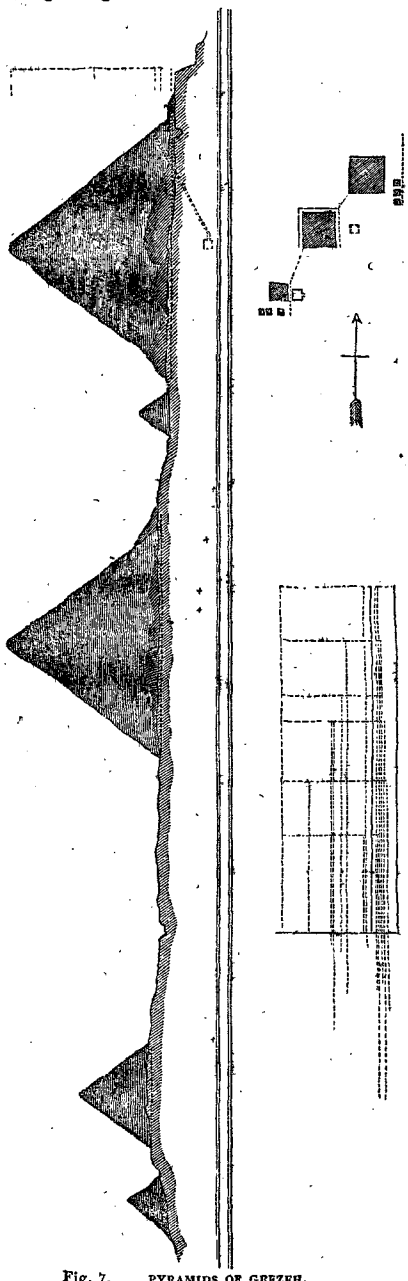


Fig. 7. PYRAMIDS OF GEEZEH.

By a series of levels, that were carefully taken by the French engineers at the end of the last century, it was found that the surface of the Arabian Gulf at Suez, at high water, was thirty-two feet six inches above that of the Mediterranean at Tyneh at low water; and it is interesting to inquire how the waters were retained in the canal, with such a difference of level. Diodorus Siculus (lib. i. cap. 1.) states, that gates or sluices were ingeniously constructed, which opened to afford ships a passage through, and then were quickly shut again; and Strabo (lib. xvii.) mentions a euriplus (a single or perhaps a double gate), which Ptolemy II. (Philadelphus) constructed, when he completed this work, and which afforded an easy passage from the sea to the canal.

Pyramids. — Of the numerous pyramids found in Upper and Lower Egypt, only those of Geezeh are mentioned by Herodotus, and were the first examined by the moderns.

In Nubia, there are remaining upwards of eighty, constructed in stone, and burnt or unburnt brick; at Aboóseer, Aboóroash, Sakkarah, Dashour, Assur, Nourri, and many other places, at a distance of several hundred miles apart. The date of the earliest has been assumed as upwards of 2000 years, and of the latest as 600 years, before Christ.

The absence of all hieroglyphics, as well as any indication of an arch, in those of Geezeh, near Cairo, have occasioned most writers to consider their origin as earlier than the others.

These pyramids, nine in all, are built on a projection of the Libyan chain of mountains, where the calcareous rock has been reduced to a level platform; but what quantity of the original mountain was left to form a core of the several structures has not as yet been thoroughly ascertained. Had the emperor Napoleon's orders been carried out, we should, by the demolition of one of those most ruined, had the means of accurately judging of their construction.

These royal sepulchres bear so strong a resemblance to earth-works and tumuli, that they appear to have had a common origin; the sepulchral chambers, which contained the entombed, are usually hollowed out of the native rock; above which is a mass of superstructure, either of solid masonry, or, as we suppose, only partly so. The kings of Egypt appear to have been the first who thought of covering their mounds with regular courses of masonry. That mountains could be easily transformed into pyramids we can readily conceive; and by a judicious cutting, as much might be taken away as would afford a sufficient quantity of stone to build up the several courses to the apex; and in all probability such a practice suggested to Denocrates the idea of converting a mountain into a nobler figure, and astonishing the world by carrying out a more useful application of such labour.

The platform upon which these pyramids are based is in length about 6890 feet, and in width, from north to south, about 4920 feet. The rock contains many fossils common to limestone, as nummulites, belemnites, oysters, &c. &c.; the French engineers took great pains in ascertaining its height above the mean level of low-water in the Nile, which they found to be about 164 feet.

What is most interesting in the study of these vast and ancient structures, is the manner in which the materials were worked, transported, and lifted to their respective levels; and finding, as we do, among the earlier pictures and bas-reliefs discovered in Egypt, the same tools represented in the hands of the mason as we use at the present day, as the round-

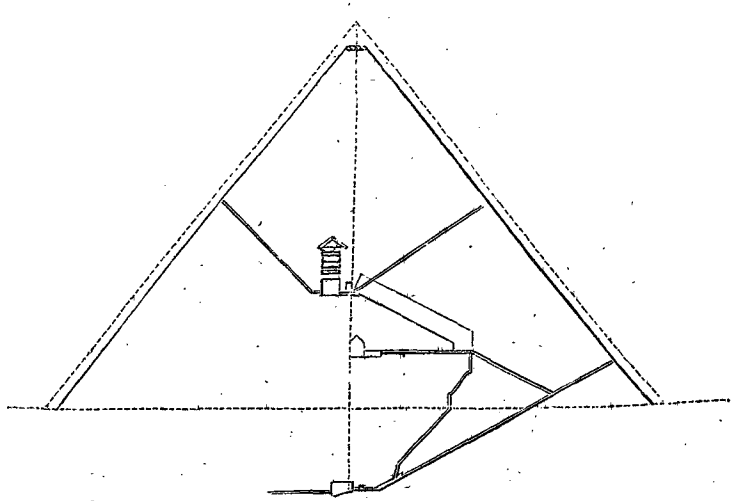


Fig. 8. GREAT PYRAMID.

headed wooden mallet and chisel, we have no difficulty in accounting for the fine surfaces and the nicely made joints which the stones in some instances present to us; and the causeway extending in length more than 3000 feet, with a breadth of 60, and height of 48 feet, we can also imagine the same facilities for the transport of materials were contrived and adopted as by us at the present day. Herodotus says, "that when the Great Pyramid was designed, that the workmen might more easily move the stone, this causeway, which is contiguous to it, was formed: its length was five stadia, its breadth ten orgyes, and its height eight." This was not the causeway seen by Pococke, the length of which he traced for upwards of 1400 feet, after which it was buried in the alluvial deposit of the inundation. It was, at a later time,—probably when used by the caliphs and Memlook kings to carry away the stones for the construction of the several mosques they raised,—repaired and strengthened by sixty-one circular buttresses, placed about 30 feet apart, and each having a diameter of 14 feet.

The causeway mentioned by Herodotus still remains in part, and reached to the west side of the canal which communicated with the Nile; and hence the blocks of stone, brought from the east side of the Nile, were easily moved along this inclined plane, to the level platform where they were required for the casing of the pyramid.

The base of the Great Pyramid is a square of 764 feet. This measurement was taken by M. Jomard, on the side to the north, after digging down to the true base; and the total perpendicular height was also found by him to have been 479 feet. Since that period, Mr. Perring has given us the following dimensions, from accurate measurement: —

The former base	764 ft.	0 in.
The present do.	746	0
Perpendicular height	450	9
Former inclined height	611	0
Present do.	568	3
Perpendicular height by casing stones	480	9

The total area of the base was 13 acres, 1 rood, 22 poles, and at present it covers 12 acres, 3 roods, and 3 poles. And supposing the rock to average 8 feet in height only over the whole extent of base, after deducting the hollow passages and chambers, Mr. Perring calculates that the quantity of stone originally used amounted to 89,028,000 cubic feet, or about 6,848,000 tons.

The present quantity of masonry, supposing it solid, is about 82,111,000 cubic feet, or 6,316,000 tons; the space occupied by the chambers and passages being taken at 56,000 cubic feet. Dr. Clarke observes that the stone used was a grey limestone, and rather more compact than that called clunch, and that when it was struck with a hammer it exhaled a fetid odour. Denon describes this pyramid to have had 208 courses in height.

The outside casing stones were found (*fig.* 9.), at the bottom, in their original position,

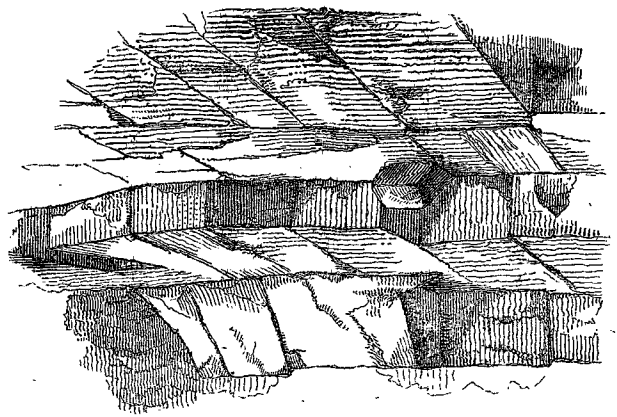


Fig. 9.

near the centre; they were quite perfect, and had been hewn to their required angle before they were built in, and appear to have been afterwards polished down to one uniform surface. They were cut to an angle of 51° 50′, and were in height 4 feet 11 inches. At the base they measured 8 feet 3 inches, and on the inclined side 6 feet 3 inches. Where they were jointed, the cement which interposed was so remarkably fine a layer, that it was scarcely perceptible.

The entrance to the Great Pyramid is at a height of 49 feet from the base, and the distance from its centre is 24 feet 6 inches from the centre of the pyramid. It is now accessible by means of the accumulation of the rubbish at the base.

The opening by which it is entered is only in breadth 3 feet 6 inches, and in height 3 feet 11 inches. Over it, to discharge the weight, lies a stone lintel, 12 feet 6 inches in length, and 8 feet 6 inches in height; above which lies another horizontal stone, not quite so long, over which four others, inclined in the manner of a pediment, act as an arch. The two lower of these inclined stones are 7 feet in height, and the two upper 6 feet 8 inches. (See *fig.* 10.)

The passage from the entrance continues of the same size as the aperture, and descends, at an angle of 26° 41′, to the length of 320 feet 10 inches, where it terminates in a chamber, the roof or ceiling of which is 90 feet 8 inches below the base of the pyramid. The length of this chamber from east to west is 46 feet; its breadth from north to south, 27 feet 1 inch; and its height 11 feet 6 inches. The northern side of this room, hollowed out of the rock, is 8 feet from the centre of the pyramid northwards, and its eastern side is 26 feet from the centre of the pyramid eastwards. This chamber was left unfinished; and in the wall opposite the entrance is a small passage, extending 52 feet in a southerly direction; and in the floor has been recently excavated a well 36 feet in depth, which has not led to any further discoveries in that direction.

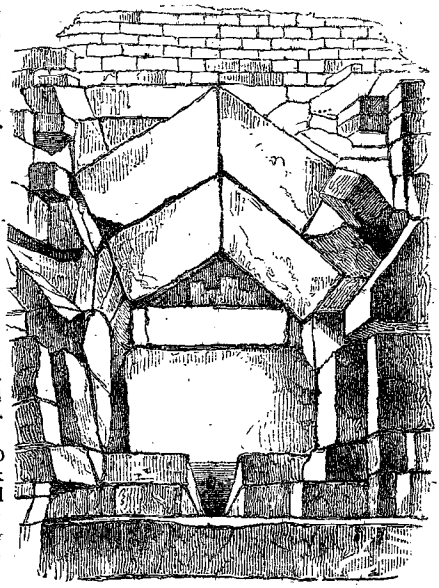


Fig. 10.

In the inclined passage, at about 100 feet from the entrance, a granite block closes up the way, which has occasioned an opening to be made at the side of it: passing through this is the ascent to the great gallery, on entering which to the right is a well, communicating with the inclined passage which led to the lower chamber: this passage is 28 inches square; at first vertical, then inclines, is again vertical, and then, with two other inclinations, unites with that below: the well is nearly 200 feet in depth, and by it the workmen are said to have descended, after they had closed the lower end of the upper passage with the block of granite above described: they then descended to the lower passage, followed it to the mouth, and made their exit.

Passing the entrance, and proceeding about 63 feet, instead of a continued descent, there is an ascent by another passage, which commences at this point, and which is in length 124 feet 4 inches, which conducts to the great gallery of the king's chamber. The angle at which this passage inclines is about 26° 18′, its height is 3 feet 11 inches, and its breadth 3 feet 5½ inches.

The great gallery follows in the same inclination with this passage, and is in length 156 feet; the breadth 3 feet 5½ inches, besides the breadth of each ramp, which is 1 foot 8½ inches; and the vertical height of this inclined gallery is 28 feet.

At the foot of the great gallery, or rather where it unites with the passage that inclines upwards, there is at the point of junction another horizontal passage, 109 feet 11 inches in length, which conducts to what is called the queen's chamber, which measures, from north to south, 17 feet; from east to west, 18 feet 9 inches; and the height, to the commencement of the roof, is 14 feet 9 inches; the extreme height is 20 feet 3 inches. The roof is formed of blocks of calcareous stone, resting, like those over the entrance, with their ends against each other. This chamber is situated nearly under the apex of the pyramid; and the stones are so well squared that their joints are hardly discernible. The floor is about 408 feet below the original summit, and 71 feet below that called the king's chamber, which is at the top of the great gallery, and entered by a horizontal passage, in length about 22 feet. This horizontal passage is in height 3 feet 8 inches, and in width 3 feet 5½ inches: at the end are four portcullises, in granite, each 12 feet 5 inches in height, which slide in grooves cut in the same stone at the sides, and which, when closed, completely blocked up the entrance to the king's chamber, which is in length, from east to west, 34 feet 3 inches, and in breadth, from north to south, 17 feet 1 inch; the height is

19 feet. The sides are lined with granite; and the roof, which is flat, is formed of the same quality of stone, having nine slabs, which cross the breadth of the chamber.

At the upper end is a sarcophagus of similar red granite to the lining of the walls: its length is 7 feet 6 inches, its breadth 3 feet 3 inches, and height 3 feet 5 inches; so that it was just admissible through the portal or entrance passage. There are upon it neither sculpture nor hieroglyphics.

The most remarkable feature or accompaniment of this chamber, is the two air-channels, or funnels, which pass directly to the outside, and commence at a height of 3 feet from the floor. The air-channel to the north is 233 feet in length, its breadth is 9 inches, and its height 9½ inches. The length of that on the south is 174 feet 3 inches, its breadth 8 inches, and its height 9 inches. Where they pass through the outer face of the pyramids, they are, as measured on the inclined face, 333 feet 1 inch from the base. These tubes no doubt were intended to produce a free circulation of air through the chamber, and bear a resemblance to the funnel of a chimney: by an admission of air the lamps were probably kept burning some time after the chamber was closed.

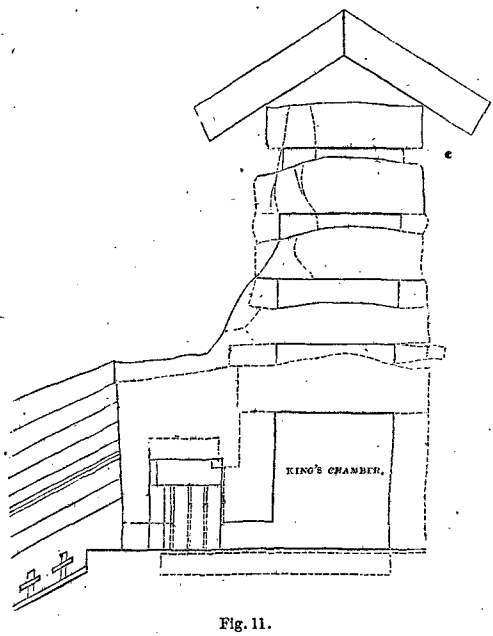


Fig. 11.

From the base of the pyramid to the floor of the king's chamber is 138 feet 9 inches; and the northern side is distant from the centre about 16 feet 3 inches southwards, and the eastern side is 26 feet 3 inches eastward of the centre line.

Over this chamber are five others, which are about 38 feet by 16, and their heights vary from 1 foot 4 inches to 8 feet 7 inches (*fig.* 11.); the height from the floor of the king's chamber to that of the upper of the five is 69 feet 3 inches.

These five chambers were evidently contrived for the purpose of relieving the weight from the ceiling of the king's chamber below, as they were only entered by cutting or forcing a passage through the solid mass to arrive at them. These rooms are divided by immense granite blocks, and the upper one has inclined blocks like those at the entrance.

The great gallery is formed by projecting the courses of stone as they are laid one over the other, so that at the top the sides approach nearly, to allow of its being more easily covered.

The outer stones of this pyramid are laid in regular courses, and we find them, as described by Herodotus, very strongly cemented together: this author also informs us how these immense blocks, some more than 30 feet in length, were raised; he says that after the first course was laid, machines, constructed of short timbers, were placed upon it, which hoisted from step to step the various blocks as they were brought along the inclined plane.

Goguet has given the form of such a machine, which consists of a timber frame containing a fulcrum, to which a long lever could be applied, worked by many men at one time, and capable of raising weights far greater than any we find used here.

Each course being so much within that below, it formed a sort of stairs, so that such a machine as is now described could be readily applied, and would serve to raise the blocks from one step to the other.

Such is the manner probably adopted by these early engineers to pile one stone upon another; and, by the magnitude of the masses they constructed, they hoped to render their work immortal. They are as solid as they are immense; and all the means that could be found to render them so were adopted. No timber enters into their construction, and the stones used are of great dimensions, and always solidly bedded.

Second Pyramid. — Its construction, though similar, is inferior to that already described, and by Herodotus is called that of Chephren. The lowest tier of stones was granite, but the rest has been brought from the Arabian mountains, the Troici lapidis mons of Pliny, or from the Mokattam limestone quarries.

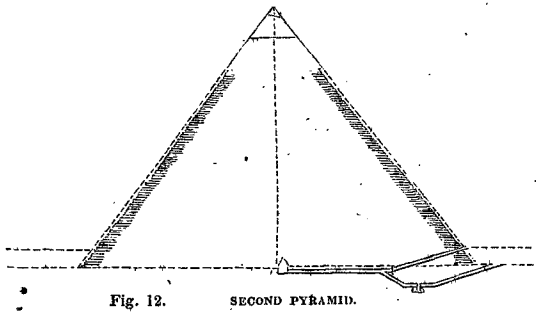


Fig. 12. SECOND PYRAMID.

The passages are also similar to those of the first pyramid, and there is only one chamber, in the floor of which the sarcophagus was sunk. There were two original entrances, but no gallery.

The casing has been removed to within 130 to 150 feet of the present summit.

	Feet.	In.
The original base measured, according to Mr. Perring -	707	9
The present do. - - - -	690	9
The former perpendicular height was - - -	454	3
The present do - - - -	447	6
Former slant height - - - -	572	6
The present do. - - - -	563	6

The angle is 52° 20′, and the size of the square platform at the top 9 feet.

This pyramid does not rise from the level of the natural rock, but out of an excavation made in the solid rock, there being a deep cut entirely around it. It was opened by

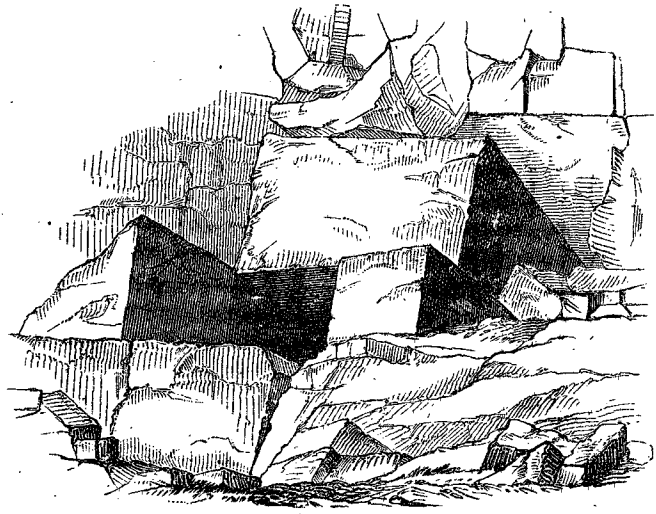


Fig. 13.

Belzoni, who found the entrance (*fig.* 13.) on the north side, which was 4 feet high, 3 feet 6 inches in width, and formed of large granite blocks. This entrance was east of a vertical meridian plane bisecting the pyramid.

At this upper entrance, which was 37 feet 8 inches above the base, the passage descended at an angle of 25° 55′; its length is 104 feet 10 inches. This passage was cut out of the solid calcareous rock. After passing a portcullis formed by a block of granite sliding in grooves, at the end of a horizontal passage was the main chamber, also cut out of the solid rock, in length 46 feet, and in width, from north to south, 10 feet 2 inches; the height at the sides, 6 feet, and in the centre, 8 feet 5 inches; the roof slanting, and covered with blocks of calcareous stone.

Making an allowance of 8 feet of solid rock over the whole area of the pyramid, the

original quantity of masonry has been estimated at 65,980,000 cubic feet, or 4,883,000 tons; and the original base has an area of 11 acres, 1 rood, 38 poles.

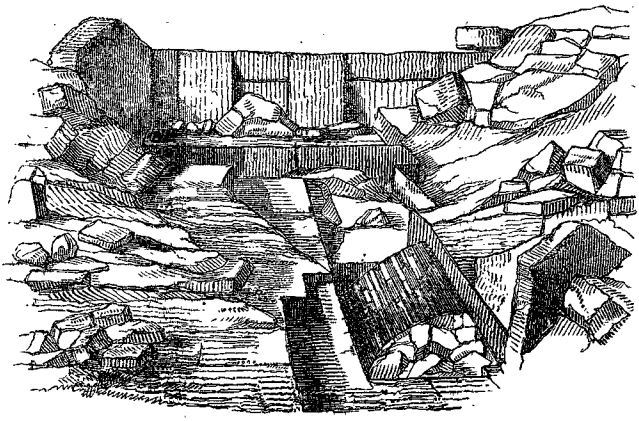


Fig. 14.

The lower entrance was at a level of 40 feet below the base line, and was completely filled up with solid masonry, closely jointed and well cemented together: the stones were 10 feet in length, or more. (See *fig.* 14.)

Third Pyramid, is that of Mycerinus, son of Cheops (*fig.* 15.). According to Herodotus, its entrance was also, like that of all the others, on the north side.

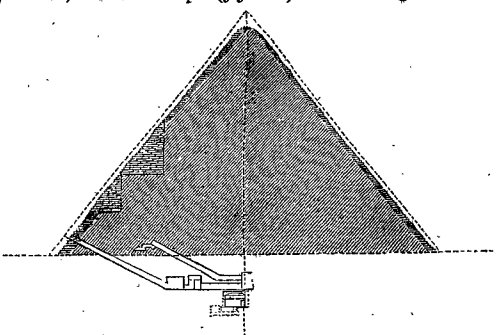


Fig. 15. THIRD PYRAMID.

Mycerinus, Moscheris, or Mencheres, as he has by other writers been called, succeeded Suphis, Saophis, or Cheops, who was cotemporary with Abraham, about 1920 years before Christ. The memory of Mycerinus was greatly revered by the Egyptians, because he excelled all his predecessors in the equity with which he administered the laws; and Herodotus observes, that this monarch was never happy after the oracle at Butos had informed him that his death would be certain at the end of six years. He endeavoured to forget the destiny which he knew was immutable, and caused a number of lamps to be made, by the light of which, when evening approached, he passed his hours in the festivity of the banquet.

Before a platform could be obtained for this pyramid, it was necessary, on the western side, to build up a foundation with two tiers of very large blocks of stone. This structure was more carefully executed than the two already described; it varied from them also in being built in regular steps or stages; the angles between the upright and horizontal faces being afterwards filled in with polished granite to form a casing.

The entrance was above the level of the base, at a height of 13 feet; and all the passages and excavations to form chambers were cut in the solid rock.

The exterior presents one continued line to the eye, but the courses of stone diminish in height as they approach the top.

	Feet.	In.
The base, which is square, is in length on each side	354	6
The present perpendicular height	203	0
The present inclined height	261	4
The former perpendicular height	218	0
The former inclined height	278	2

The angle at which the casing is laid is 51°, and the square platform at the top is about 16 feet.

The inclined passage is on an angle of 26° 2′, and is in length 104 feet; in breadth, 3 feet 6 inches; and in height, 4 feet: at a distance of 4 feet 3 inches is an ante-room, which, from north to south, is 12 feet in length, 10 feet 5 inches in breadth, and in height 7 feet. There are then three portcullises, in length 13 feet 5 inches; and an horizontal passage, 41 feet 3 inches in length, 3 feet 6 inches in breadth, and 5 feet 10 inches in height. At the end of this is a large apartment, which had a flat ceiling, the total length of which is 46 feet 3 inches, and breadth 12 feet 7 inches, the height being about 13 feet 6 inches.

Beyond this was the sepulchral chamber, the length of which, from north to south, was 21 feet 8 inches; and the breadth 8 feet 7 inches; the height at the sides 8 feet 9 inches, and in the centre 11 feet 3 inches.

In this chamber Colonel Howard Vyse found the stone sarcophagus which contained the wooden coffin now in the British Museum, which has on it the name of the King Mencheres or Mycerinus.

The plan of the inclined passage conducting to the sepulchral chamber shows its direction and the situation of the portcullis, where an additional width is given for the purpose of rendering this part more secure. The whole forms apparently an impassable barrier; and without a knowledge of the construction of this portion of the gallery, and the aid of machinery, a passage could not have been obtained. Over the great chamber the position of the large stones which cover it are indicated. The section over the plan exhibits two inclined galleries, one above the other, and nearly parallel: the upper gallery has not been traced to the outside, but may conduct to another chamber not yet discovered. As the latter inclined gallery has its communication with the upper part of the chamber which contained the sarcophagus, it is by some supposed to have been used merely as an air-shaft; but this is only a conjecture, its dimensions being considerable. The masonry of both the inclined galleries is executed with the same care, these being apparently cotemporary with the original structure.

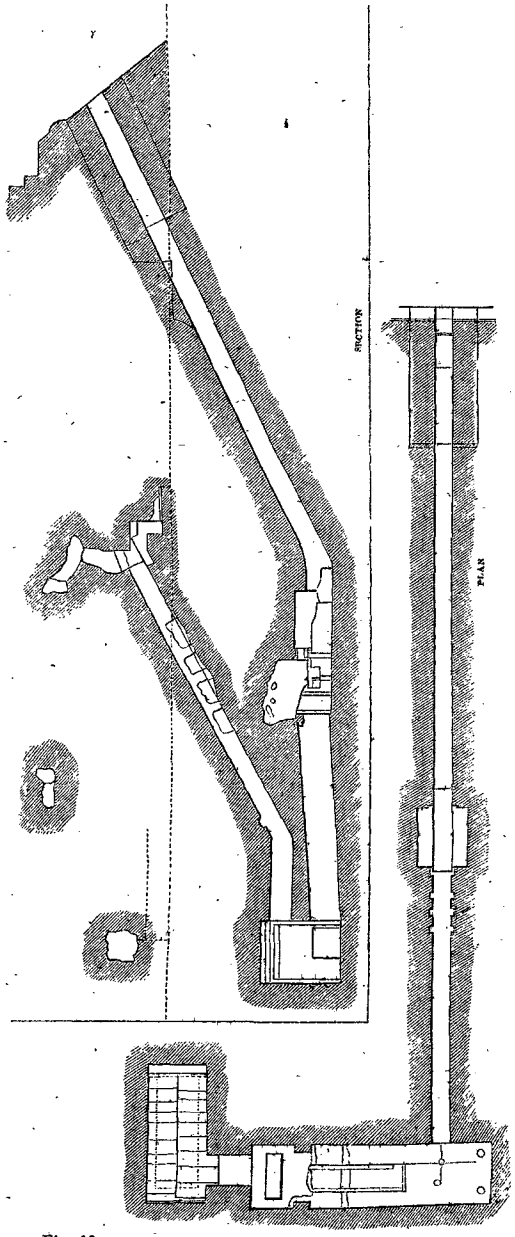


Fig. 16. PYRAMID OF MYCERINUS.

The entrance to this inclined passage, which was at the height of 13 feet above the level of the base, was formed by a square hole (*fig.* 17.), or rather by the leaving out of one large stone: the joints of the masonry around it were very imperfect, and many of them seem to have been disturbed as if injured by attempts to force an opening at some time or other.

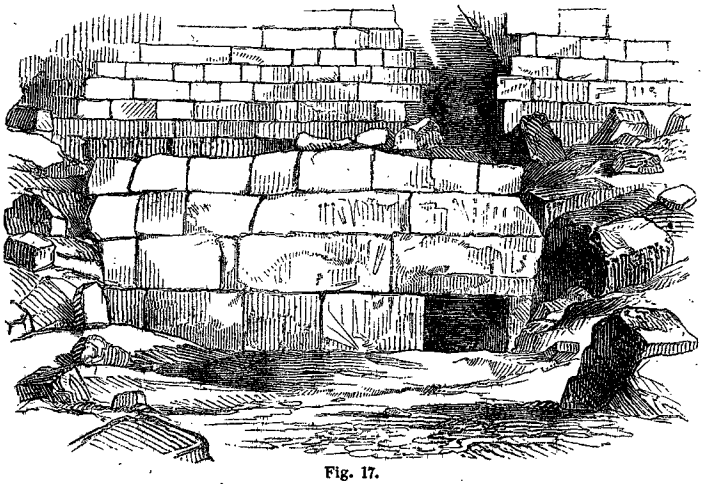


Fig. 17.

The ante-room, which occurs in the lower passage, at 104 feet from the entrance, is peculiar for the contrivances which are introduced to prevent any one from proceeding beyond it. Where the three portcullises are placed (*fig.* 18), across from east to west, the passage is

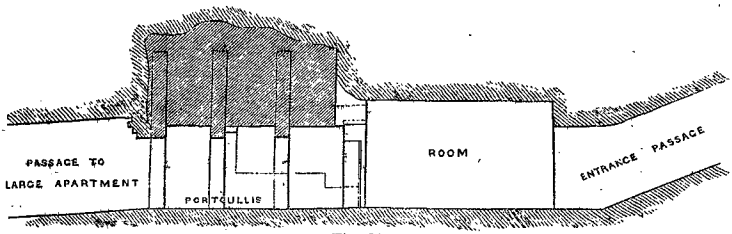


Fig. 18.

13 feet 6 inches in length; after which the passage proceeds to the large apartment in nearly a horizontal line. Immediately above, in the section of this portion of the pyramid, may be seen another passage, nearly horizontal at first in its direction, and afterwards inclining upwards: it however terminates at that part of the pyramid where the artificial construction commences; which seems to indicate that it never had any communication with the exterior.

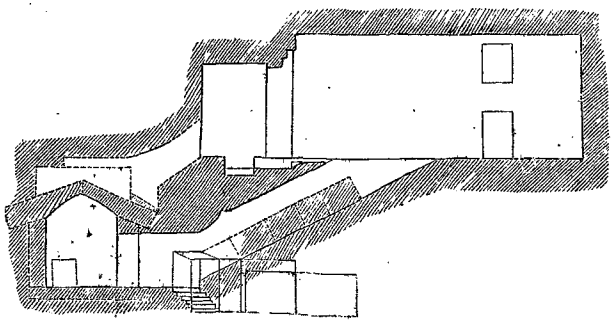


Fig. 19.

The other end of this passage, where it is attached to the large apartment, is very much cut by ropes, the stone indicating, by the grooves worn in it, that hoisting had been much practised here: probably the stones from the excavations may have been drawn out by means of this passage, and afterwards used in the upper constructions, which now effectually close the other end.

The centre of the pyramid is immediately over the cross, marked on the plan of the large apartments in *fig.* 16. At the bottom of the southern side of a passage which leads from the sepulchral chamber, a recess has been formed, on the opposite side of which is a flight of seven steps which conducted into the southern end of a room that had its floor 3 feet below the level of that of the passage. This room was of a rectangular form, but was not set out square with the great chamber; it contained four niches or compartments on the eastern side, and two on the northern.

The large apartment shown on the plan, *fig.* 16., and lying at right angles with the entrance passage, had a flat ceiling of very large and massive stone, and was divided in its length by two projections or pilasters, one of which was attached to each side, and beyond was the recess or sepulchral chamber, in which the sarcophagus was found: the hole in front conducts below. (See *fig.* 20.)

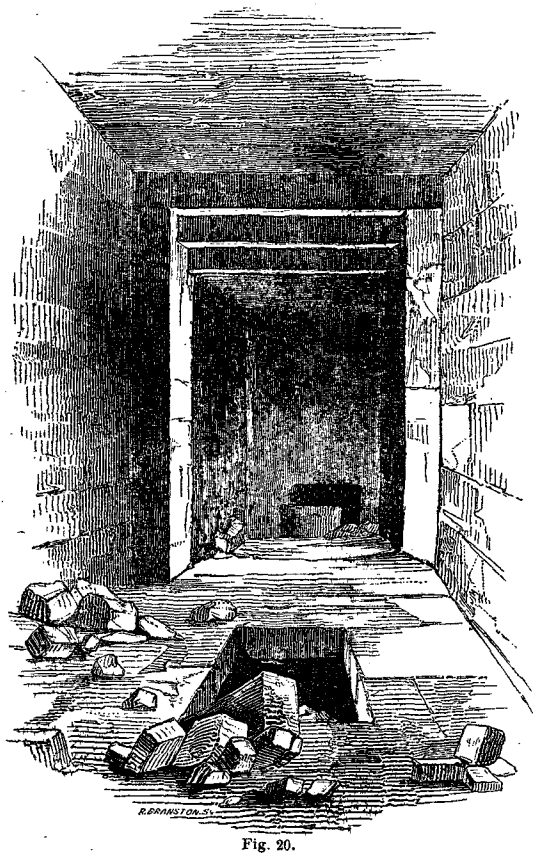


Fig. 20.

The original quantity of masonry in this pyramid has been estimated at 9,132,000 cubic feet, or 702,460 tons, and the extent of its base at 2 acres, 3 roods, 21 poles.

The discovery of the sarcophagus settles the question relative to the destination of the pyramids. The chamber which contained it is given in *fig.* 21., and indicated in the plan, *fig.* 16., where the recess is shown beyond the two pilasters. All the ancient writers bear testimony to the extreme anxiety of the Egyptians, in common with other nations, to preserve their remains until a period unanimously anticipated, when their bodies should be resuscitated. Indeed, the Egyptians, according to Diodorus Siculus, set little value on the shortness of this present life, but put a high esteem upon the name and reputation of a virtuous life, after death; and they called the houses of the living, inns, because they sojourned there a short time; but the sepulchres of the dead they denominated lasting habitations, as in them they were to abide for infinite generations. For this reason they did not bestow much care on the building of their houses; but in beautifying their sepulchres, they left nothing undone that could be thought of.

When a king died, there was a universal mourning and a rending of garments. Temples were shut up, and feasts and solemnities stayed, for the space of seventy-two days; casting dust upon their heads, and girding themselves under the breasts with linen girdles. When these and other observances had been performed, all things were then prepared in a stately manner for the funeral; and on the last day, the coffin, with the body inclosed, was brought

to the entrance of its final sepulchre, where, according to the laws of Egypt, all the actions of the individual during life were rehearsed, and any one had free liberty to expatiate on his faults. The priests, then, with many thousands of the people, amidst profound silence, assisted in depositing the coffin in the sarcophagus prepared to receive it, which was adorned with painting.

It is not improbable that the hole in the pavement in front of the sarcophagus (*fig.* 21.), communicated with a channel which carried off the water brought down by the inclined passage, should any filter through the walls or rocks with which it was connected. When Belzoni advanced some distance along the passage which led to the apartment containing the splendid sarcophagus in the museum of Sir John Soane, he found a well 30 feet in depth, and 14 feet by 12 feet 3 inches, which was contrived for the purpose of receiving the rain water, and keeping the other chamber dry. Heavy rains fall at Thebes occasionally, once in every four or five years, when it may enter through the porous stone in sufficient quantity to wash down the rubbish constantly found deposited within these passages and chambers.

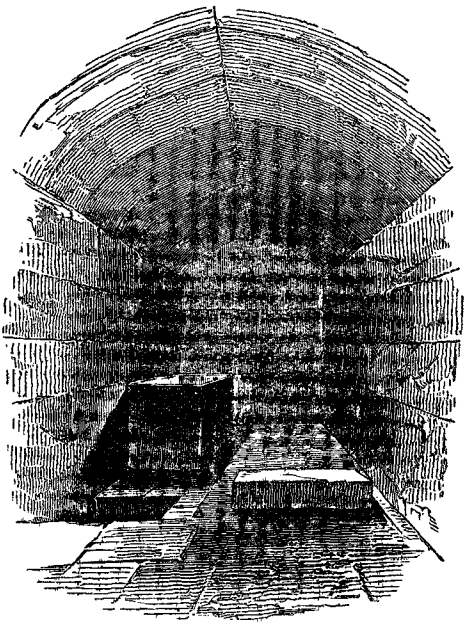


Fig. 21.

Fourth Pyramid. Its square base is only 102 feet 6 inches long on each side, and its total height 69 feet 6 inches. It is constructed with large blocks of stone; but it is doubtful whether the exterior was ever completed. The sepulchral chamber measures 19 feet 2 inches from north to south, its breadth 8 feet 9 inches, and its height 10 feet 4 inches. The entrance to this pyramid is by a square aperture. (See *fig.* 22.)

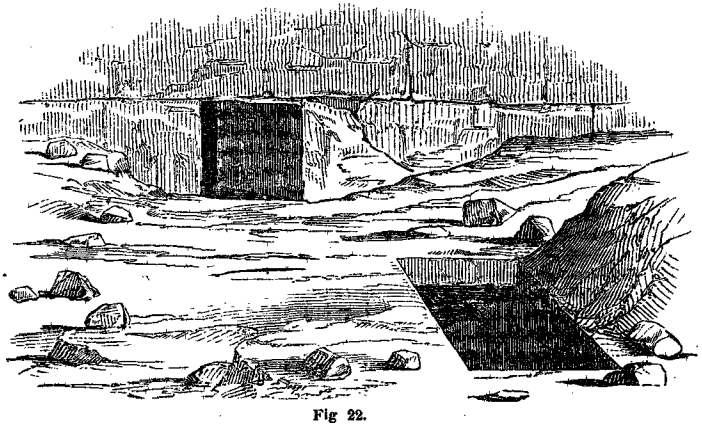


Fig 22.

The fifth Pyramid was 145 feet 9 inches on each side at the base, and its original perpendicular height 93 feet 3 inches. Its chamber, from east to west, was 25 feet 6 inches, its breadth 10 feet 5 inches, and its height 8 feet 9 inches; its entrance is by a descent. (See *fig.* 23.)

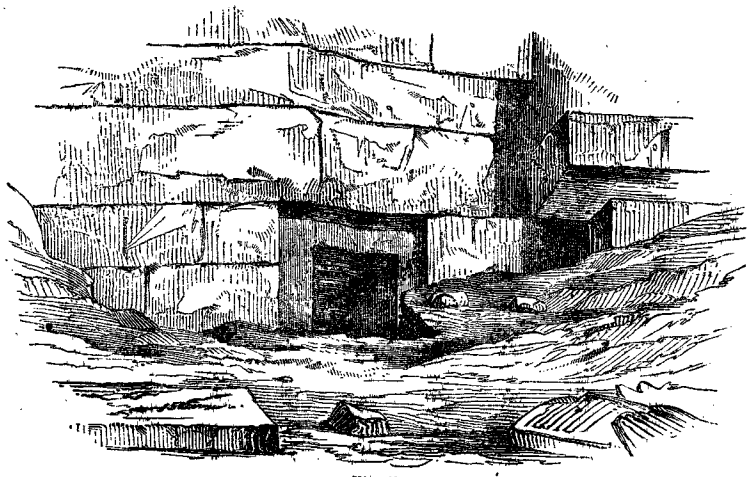


Fig. 23.

The sixth Pyramid measured at its base 102 feet 6 inches, and had a total height of 69 feet 6 inches. It contained, besides its passages, an ante-room, and sepulchral chamber, which was in length, from north to south, 26 feet, in breadth 11 feet 4 inches, and in height 24 feet: the entrance here is by descent also. (See *fig.* 24.)

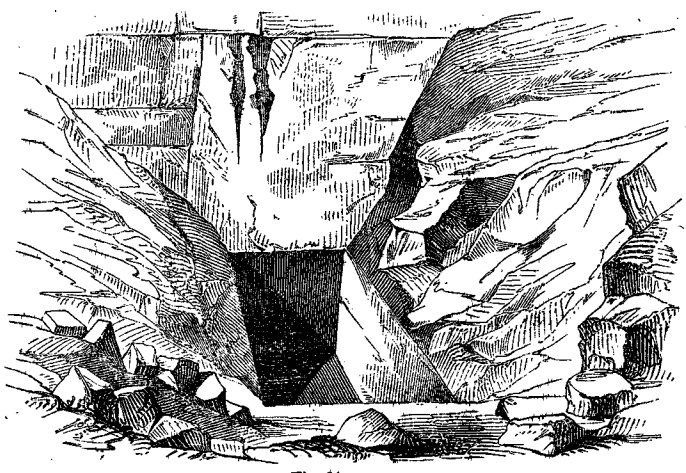


Fig. 24.

The seventh Pyramid had its passage lined with masonry, and its sepulchral chamber with highly-wrought square slabs of stone: its dimensions were, from east to west, 11 feet 8 inches, and from north to south 9 feet 9 inches.

The length of one side of its square base was 172 feet 6 inches, its perpendicular height 111 feet, its inclined height 140 feet, and the angle of its side 52° 10′.

When the enterprising Belzoni was in Egypt, he attempted to open most of these pyramids, and had considerable difficulty in finding out the entrance, which was not always in the centre, or at an equal distance from the angles; much time was spent in vain upon the pyramid in question, and it is to Mr. Perring and his patron that we are indebted for the means of describing the entrance shown above.

The stones in this pyramid, like the others, were laid in distinct courses, diminishing successively in size as they approached the top: each course was so much within the other below, that it formed a sort of stair previous to the casing stones being laid upon the outside, which rendered the work complete. These steps served for the placing of the

machines mentioned by Herodotus, by which the stones were successively raised step by step, and imbedded in their proper places; after which the coating or casing commenced at top, and the work was finished by progressing downwards; at least so it is reported by the father of history.

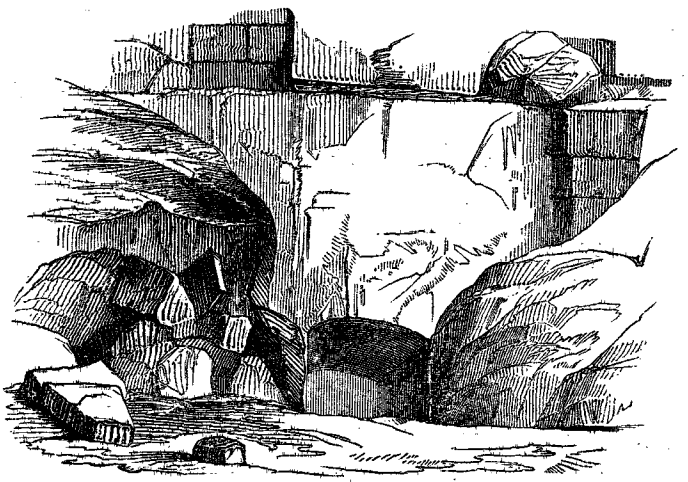


Fig. 25.

The eighth Pyramid had a square base, the side of which was 172 feet 6 inches in length, a perpendicular height of 111 feet, an inclined height of 140 feet, and the angle of its side was 52° 10′. The sepulchral chamber was in length, from east to west, 12 feet 9 inches, and its breadth 10 feet 3 inches; its entrance is very much broken. (See *fig.* 26.)

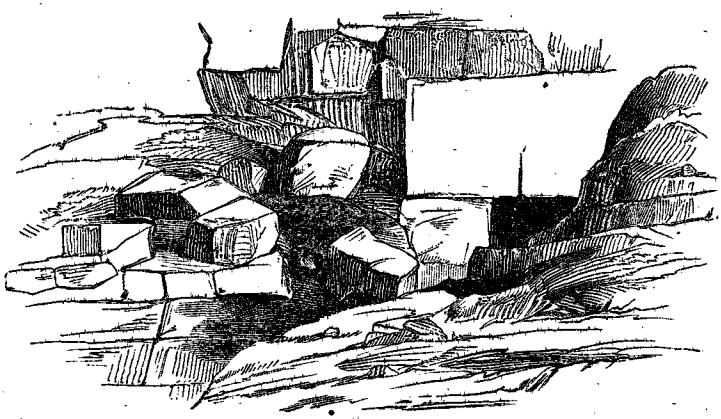


Fig. 26.

The ninth Pyramid measured on each side at its base 160 feet: its perpendicular height was 101 feet 9 inches, and its inclined height 130 feet 6 inches. The angle that its sides formed was 52° 10′. Like the others, it had passages, an ante-room, and a sepulchral chamber, which was in length 12 feet 3 inches, in breadth, from north to south, 3 feet 6 inches, and in height 8 feet 6 inches. The entrance is very much broken, and appears to have been greatly disturbed; it was by descent, like most of the others; the stones which formed it were of enormous dimensions, and laid with great care; that which served as a lintel weighed many tons, and must have required the aid of a powerful lever to lift it into its place. By means of an inclined plane, these large blocks were rolled from their quarries, after which the machine mentioned by Herodotus was made use of.

These pyramids astonish us by the enormous manual labour bestowed upon them.

Herodotus describes hundreds of thousands of persons as employed for their construction, who were changed every three months; years were consumed in the preparation of the material; millions sterling were expended in the purchase of food whilst they were in progress; and, according to some inscriptions remaining, this food consisted of leeks, garlic, onions, and other vegetable diet. In the early ages of the world, a rapidly increasing population required support before means could be found to employ it beneficially, and the sovereigns of Egypt might have been induced to construct these splendid tombs, to afford occupation to their subjects.

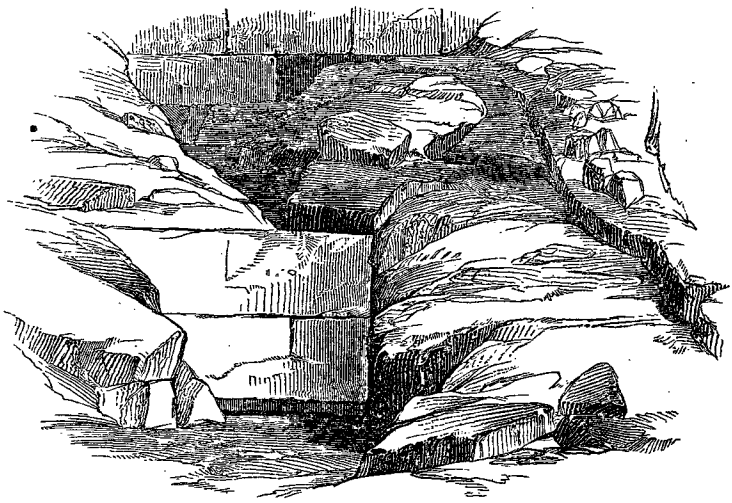


Fig. 27.

Campbell's Tomb, as it is now called, is here given on account of the arch which it contains, and which, it is asserted, was known at the time of the first Osirtasen, who reigned when Joseph was in Egypt.

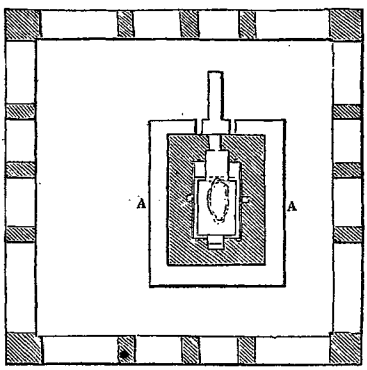


Fig. 28.

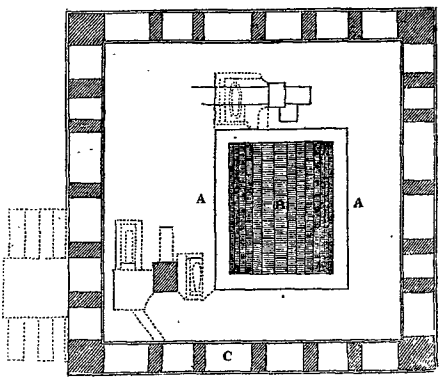


Fig. 29.

In the ground plan the chamber A A is 30 feet 6 inches from east to west, and 26 feet 3 inches in the other direction: the depth of this excavation is 53 feet 6 inches.

The part lettered B is the arched tomb, and C is a trench cut all round, 5 feet 4 inches in width; but it is not at an equal distance from the centre excavation on all sides. It forms a square, measuring on the inside about 57 feet 3 inches. This trench is cut to the depth of 73 feet, which is a little more than 15 feet 6 inches below the surface of the inundation in 1838.

On a bed of sand, 2 feet 6 inches in thickness, slabs of stone about 5 feet in length were laid flat, and upon them were carried up a few courses with smaller stones.

In the centre was placed a large block (A) scooped out to receive the sarcophagus, which contained the body; over this, at B, was another large stone placed, covering the whole, and on the lower edge was an inscription, or row of hieroglyphics. This sarcophagus, of black basalt, is now in the British Museum.

The entrance was by the pit *h*, and the roof of the chamber was formed of four stones, the two outer being set edgeways, and inclined inwards, having the two others placed upon them, forming as it were the first rudiments of an arch.

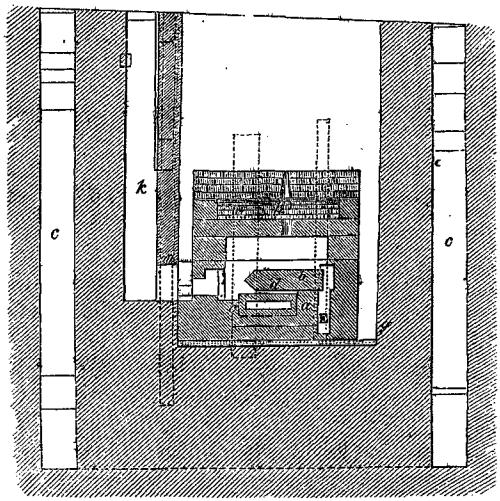


Fig. 30.

Over these was turned an arch, the radius of which was 6 feet 2 inches, and the span 11 feet, which is a little less than that of a semicircle. It is composed of four courses, 3 feet 10 inches thick; the stones are described to have been 4 feet long, and 15 inches in breadth; at the back the joints were packed with chips, and the whole had been grouted with fluid mortar. (See *fig.* 31.)

The antiquity of the arch is said by Mr. Wilkinson, in his "Egypt and Thebes," to be traced to the time of Amunoph the First, who reigned 1540 years before Christ; and arches of stone and brick are met with in several tombs of a very early date. He also observes, that if the chambers of the brick pyramids at Memphis, erected by the successor of the son of Cheops, were vaulted, as he supposes, the antiquity of the arch might be carried back nearly 700 years prior to the reign of Amunoph, which is 2020 years before our era.

When blocks of stone, cut like truncated wedges, are so placed that they support each other by their mutual pressure, they constitute an arch in our acceptation of the term; and it does not seem improbable that such a system of construction should result from the use of bricks, in a country where timber was not readily obtained, to serve as lintels or discharging pieces. Brick arches seem the first upon record; here the opening is gathered over by three stones set in the ordinary Egyptian manner, and the arch in question, turned over them, bears no weight, but acts simply as a covering; there is no indication of an abutment necessary to render the work solid and durable.

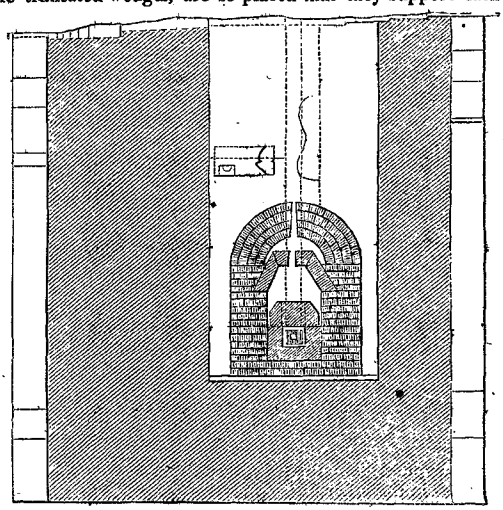


Fig. 31.

Mr. Wilkinson observes that arches, or similar constructions, in brick, were in use 3370 years ago, as the name of Amunoph is preserved on the stucco which coats the interior of the vaulted tomb at Thebes. The stone arch at Saccara still exists, of the time of the second Psammeticus, who reigned about 600 years before our era, and, from its peculiar construction, there is little doubt that the Egyptians had been long accustomed to the erection

of stone vaults. The want of timber in that country would render such construction almost necessary.

In the time of the first Osirtasen, who was cotemporary with Joseph, the arch was made use of in the tombs at Beni Hassan.

In Egypt, then, we must acknowledge we find the first rudiments of the arch; and from that country it was brought into Europe. The principle of the arch, with all its voussoirs radiating to a common centre, is certainly shown to exist in many buildings which modern travellers have surveyed in Egypt.

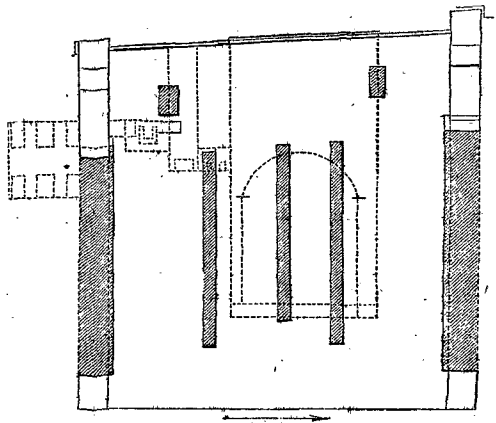


Fig. 32.

The length of the tomb is 14 feet 9 inches, the breadth is 10 feet 5 inches, the height to the springing of the arch is 19 feet 4 inches, and from the springing to the top of the arch is 7 feet 8 inches. A tube of earthenware in a stone stopper had formed an opening between the two apartments, and above it another, with a similar stopper in the arch, for the purposes of ventilation.

The Pyramids of Middle and Lower Egypt are thirty-nine in number: they are situated on the western side of the river, on desert hills, which form the western boundary of the Nile. They are comprised within 29° 16′ 56″ and 30° 2′ 30″ north latitude, or a space equal to about 53 English miles.

Pyramid of Abou Roash is situated five miles to the north-west of those at Gizeh. The base, which is all that remains, is 320 feet square. The mass, formed of hard chalk, of which the mountain is composed, has been cut into the form: this was cased with hard stone, none of which remains. There is an inclined entrance passage, and an apartment lying east and west, cut out of the solid chalk, and lined with fine calcareous stone from the Tourah quarries. The passage inclines at an angle of 22° 35′, and is about 160 feet in length. The chamber is 40 feet by 15, above which was apparently another. The level space around the pyramid is about 510 feet above the plain: the northern side has been sloped away, and an inclined causeway, 4950 feet in length, and 30 in breadth, leads into the plain below: this causeway is in some parts nearly 40 feet in height, and walled with masonry.

Pyramid of Zowyet el Arrian has its base about 300 feet square, and in height its remains are 61 feet above the rock: the material with which it is built is a hard limestone, in which are many fossil shells: the blocks were not squared, nor were they laid in regular courses, clay or loam being used instead of mortar.

Pyramid of Reegah is situated about three quarters of a mile north-west from those of Abouseir; its base measures 123 feet 4 inches square. This pyramid had two inclinations given to it: the lower was at an angle of 75° 20′, and the upper, covered with calcareous stone, an angle of 52°.

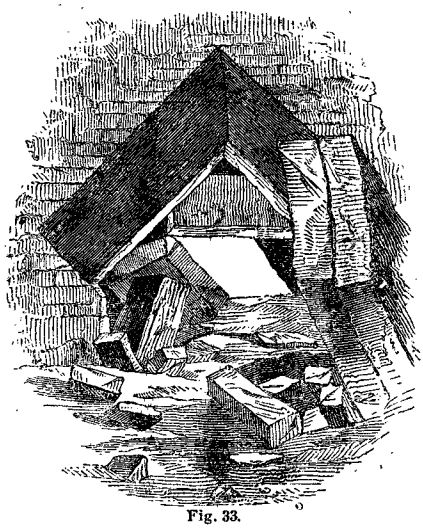


Fig. 33.

Pyramids of Abouseir are three in number: they are about seven miles S. S. E. of those at Gizeh, and three miles N. N. E. of Saccara. The material with which they are built is the stone found upon the spot, laid in Nile earth instead of mortar. The exterior casing of all of them has been removed. The interior chambers and passages are similar to all the others.

The northern pyramid was originally 257 feet square, and the perpendicular height 162 feet 9 inches; the angle of the casing being 51° 42′ 35″.

The passage descended at an angle of 27° 5′ for 14 feet, and then went horizontally: at the distance of 27 feet from the inclined plane, it had been closed by a granite portcullis 1 foot 3 inches in thickness.

The distance from the present entrance to the apartment was in length 71 feet 4 inches; the apartment measured from north to south 11 feet 8 inches; the height at the sides was 9 feet 4 inches, and in the centre 12 feet 6 inches. This apartment was in the centre of the pyramid, and there had been three tiers of roof blocks, the footings of the upper rows being carried beyond those of the lower, in order that the pressure should be more equally distributed. These roof blocks were 35 feet in length, 12 feet thick, and 9 feet wide.

The middle Pyramid had for each side of its square base 274 feet, and its perpendicular height 171 feet 4 inches. Here was also an inclined passage and a portcullis; beyond which a horizontal passage extended 63 feet in length, 5 feet 10 inches in height, and 5 feet 1 inch in width. The width of the apartment at the end was 14 feet; the roof of which had been formed of three tiers of blocks, 48 feet 6 inches in length.

Great Pyramid, which was on steps, covered with flat stones, the space between these and the pyramidal casing being filled up with rubble. The lower parts of the casing, as well as portions of the entrance passage, were of granite: the mortar in general was formed of Nile earth, with a small proportion of lime.

Its base originally measured 359 feet 9 inches, and perpendicular height 227 feet 10 inches.

The entrance passage inclined 26° 3′; and where it was continued horizontally, it was constructed of large blocks of Tourah stone, with a roof of inclined stones. The apartment was covered with a pointed roof, of three courses of blocks, 45 feet in length.

Small Pyramid, originally measured at its base 75 feet 5 inches on each side: the apartment within was in length, from east to west, 12 feet 2 inches; from north to south 10 feet 6 inches, and in height 8 feet 7 inches. At the south-eastern corner was a recess, 5 feet 1 inch in breadth, and 3 feet 5 inches in depth. The horizontal passage was in length 14 feet, in height 8 feet 7 inches, and in breadth 2 feet 5 inches. The inclined passage was 27 feet in length, and 2 feet 10 inches in breadth; the angle being 22° 10′.

Pyramids of Saccara.—The first, much decayed, is a mass of ruins; its present base measures on each side 210 feet, and its height 59, the platform at the top being about 50 feet square.

The second Pyramid is built with large unsquared stones; the length of the side of the original base is 231 feet 3 inches, its height 146 feet 6 inches. The angle of the inclined passage is 26° 35′, and its length 78 feet 9 inches. The horizontal passage to the portcullis is in length 31 feet 3 inches; the thickness of the portcullis is 2 feet 3 inches, and from thence to the chamber 26 feet 9 inches, making the total length 60 feet 3 inches: its width is 4 feet 2 inches, and height 6 feet 1 inch. The two principal apartments have pointed roofs, and are lined with calcareous stone. The outer apartment is in length, from east to west, 13 feet 7 inches, in breadth, from north to south, 10 feet 3 inches; the height at the sides is 10 feet 5 inches, and in the centre 14 feet 2 inches. The inner apartment is in length, from east to west, 25 feet 7 inches, and in breadth, from north to south, 10 feet 3 inches. The rooms at the side, one of which runs from east to west, is 18 feet in length and 8 feet in width. Another, from north to south, is in length 34 feet, and in width 7 feet 3 inches.

The third or Great Pyramid, or that of degrees, stands about 91 feet above the level

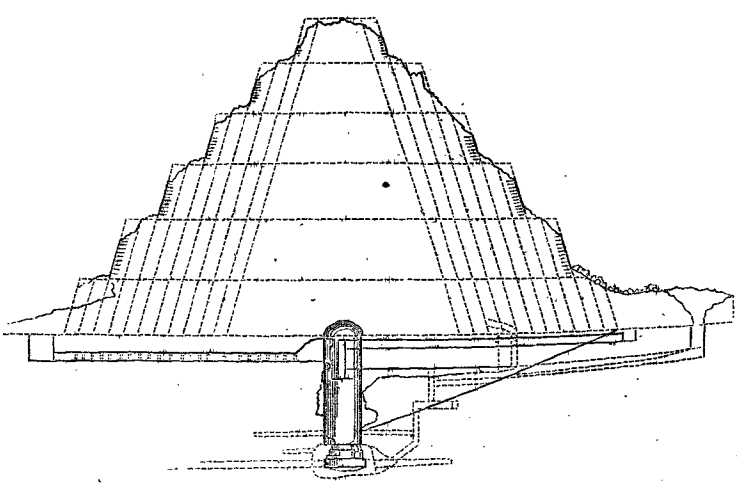


Fig. 34. SACCARA.

of the plain; an inclined way, by which the stone was drawn up, being cut in the sides of the rock. It differs from most of the other pyramids in its construction, and from its having four entrances and several chambers: originally it had on the exterior six steps or truncated pyramids diminishing upwards. The core or mass of masonry is rubble, enclosed by eleven walls, each about 9 feet in thickness, inclining inwards. These walls are built of rudely squared stone, laid on mortar made of the gravel of the desert and lime, or of Nile earth.

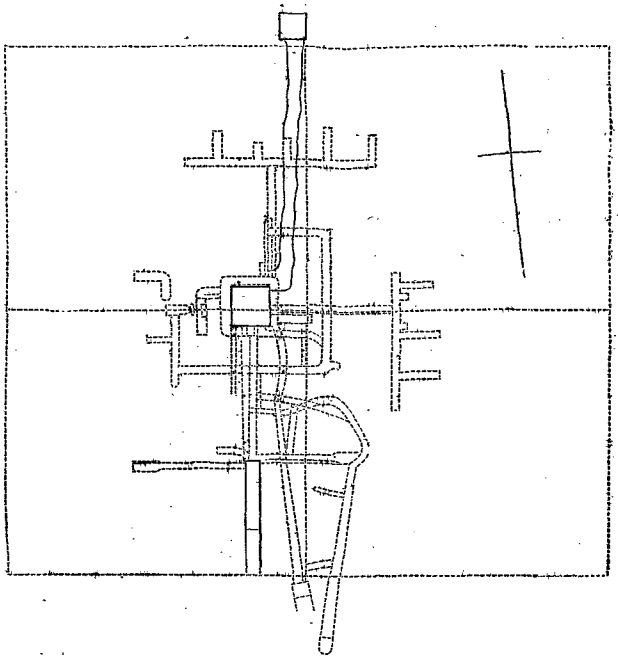


Fig. 35. SACCARA.

The length of the sides of the original base from north to south was 351 feet 2 inches, and from east to west, 393 feet 11 inches. The total area was 15,372 square yards.

The plan of this pyramid indicates the passages and galleries which led to and from the square sepulchral chamber, shown nearly in the centre; intricate as they now are, they appear to have been set around the principal room at regular distances, whatever may have been their level or height, and the regularity with which the walls are built with very coarse material, shows some advancement in the knowledge of construction. The concrete or rubble employed here is a very early indication of the use of artificial cements, which have continued to be adopted throughout the civilised world at all periods: the due proportion of lime and the other compounds experience soon taught, it being one of the properties of matter to mix only in definite quantities. The concrete of the pyramid

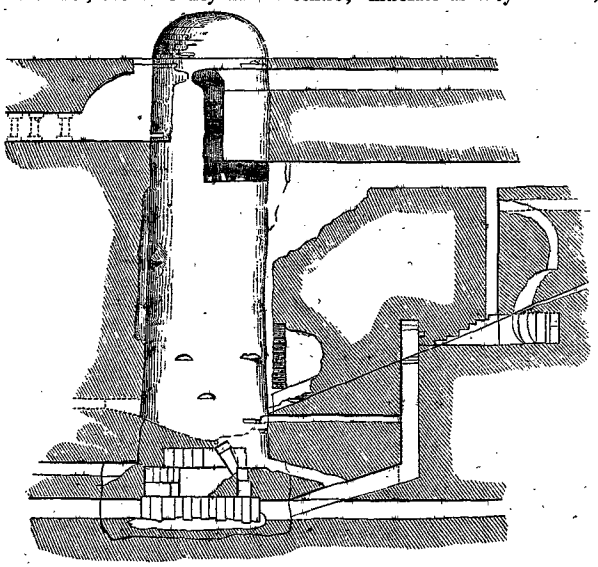


Fig. 36. SACCARA.

of the Coliseum, and our feudal castles, differ only in the quality of the lime made use of, some being so excellent, or so perfectly pure, as to unite with a greater quantity of stone than the other.

The platform at the top measured originally, from north to south, 42 feet 10 inches, and from east to west 85 feet 8 inches.

The height of the first step is 37 feet 8 inches; of the second, 35 feet 11 inches; the third, 34 feet 3 inches; the fourth, 32 feet 7 inches; the fifth, 30 feet 10 inches; the sixth, 29 feet 2 inches. The face of each story makes an angle with the horizon of 73° 30′.

At the distance of 52 feet from the pyramid, and 11 feet to the westward of the centre, is the entrance by means of a sunk pit; here commences a horizontal passage, 120 feet in length; this afterwards takes a winding direction, and descends to the large chamber. The general inclination is 23° 20′, and the width of this passage is in the centre 3 feet 5 inches; its length is 176 feet 5 inches; and its entrance to the chamber is 7 feet 6 inches above the level of the floor. There is another passage, 179 feet 6 inches in length, and in breadth and height 4 feet 2 inches, excavated out of the rock: this commences at 5 feet to the eastward of the northern front, at about 5 feet distance from the building. This passage communicates with a recess, in the upper part of the western side of the large chamber, where apparently a wooden beam had been introduced, to which a rope had been suspended: this passage was nearly straight and lying horizontal.

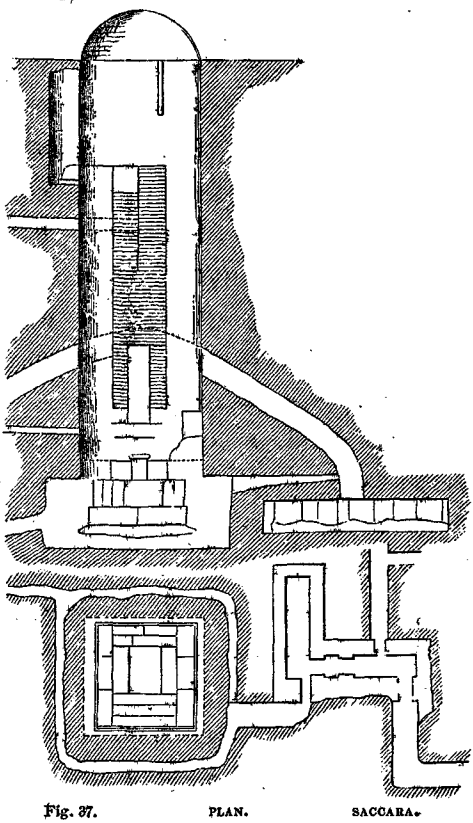


Fig. 37. PLAN. SACCARA.

At a distance of 7 feet to the eastward of the southern front was another pit, 14 feet square; from this proceeded a horizontal gallery 166 feet 3 inches long, 10 feet wide, and 6 feet 4 inches high, with a recess at the south-western angle of the large chamber; this recess was 70 feet above the level of the chamber. The whole of the passage was cut out of the rock, and its covering or roof was supported by a row of 22 columns, made of compact limestone: these columns, which are partly covered with hieroglyphics, have been wedged up above and below with wood, to catch the bearing of the superincumbent weight, to which most of them have yielded.

The large chamber is excavated out of the rock: its western side is 25 feet 6 inches to the eastward of the centre of the pyramid, from north to south; but it is immediately under it from east to west. Its dimensions are 24 feet by 23; and its height was 77 feet from the floor to the ceiling, which was found to have been formed of planks, supported by a platform of timber, consisting of two principal beams, and cross bearers: one of these beams remained in its situation, though broken in the middle.

The floor of the chamber was formed with blocks of granite, 10 feet long, 5 feet 4½ inches wide, and the same in height; its entrance was closed by a conical block of granite (A, *fig.* 38.), weighing about 4 tons. The granite blocks which compose the floor of the large chamber are in thickness about 4 feet, and supported on pillars of loose stones wedged up with wood.

From the south-western angle of the large chamber a passage communicates with the smaller rooms. The first is 20 feet 6 inches from north to south, 5 feet 1½ inch in width, and 6 feet 5 inches in height; the other is 18 feet 8 inches in length, from east to west, and of the same width and height as the last.

The sides of these apartments were lined with calcareous stone, and ornamented with bluish green porcelain; the ceiling and floor was the native rock, smoothed and plastered over.

The several chambers and galleries which conducted to them were finished and decorated in a similar manner to the houses or palaces occupied by the living, which were usually coated with a fine stucco within and without, and ornamented with devices by the painter. In some of the tombs, bronze pins have been noticed in the floors, within the openings, on which the wooden doors turned which shut in the several chambers; sometimes holes or mortices in the pavement and stone lintel above the opening are discovered, in which the pivot at the top and bottom of the door was inserted. Many bolts and bars, which secured the openings, have also been found, as have iron keys. The floors not of stone were covered with a composition, and the ceilings in many instances exhibit remains of painting; among the designs of some may be traced all that is admired in the ornaments of Greece and Rome; the fret and other familiar forms are here first met with in all their variety.

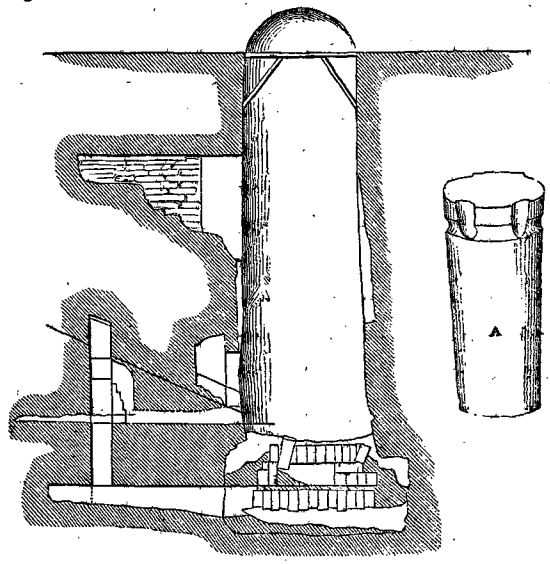


Fig. 38. SACCARA.

The fourth Pyramid has not been accurately measured, but it is about 220 feet square, and the height 62 feet, the platform at top being 30 feet.

The fifth Pyramid is the only one *entirely* constructed with quarried stone, the others being only cased with that material. The base measures 250 feet, and its height is 40 feet.

The sixth Pyramid measures at present at its base 270 feet, and in height, 80 feet.

The seventh Pyramid at its base is 140 feet.

The eighth 240 feet, and *the ninth* 245 feet: these have most of them causeways, and are built on steps.

Pyramids of Dashoors are situated near the village of Mensheeh, and are about three miles from Dashoors: they consist of two of brick, two of stone, and another, *northern brick Pyramid*, is composed of crude bricks, and has been covered with stone from the Mokattam quarries. This was supposed to have been that described by Herodotus, as built by Asychis, the successor of Mycerinus.

Many of the stones which formed the casing were at their base 8 feet 3 inches in length, 6 feet in width, and 1 foot 11 inches thick; the ends being sloped with the inclination of the pyramid: they were not laid in regular courses, but in the manner termed polygonal; several of them were held together by dovetail cramps, made of stone. The body of the pyramid was built of bricks, which were about 16 inches in length, 8 inches in width, and from $4\frac{1}{2}$ to $5\frac{1}{2}$ inches thick: they were mostly composed of alluvial earth; some with less sand, but containing a quantity of straw; and others made from a dark-coloured tenacious earth without any straw: they were all laid in regular courses, occasionally crossed by others, the interstices being filled up with dry sand.

The original base measured 350 feet, and the height 215 feet 6 inches, the angle at which the casing was laid being 51° 20′ 25″. This pyramid has at present baffled all attempts at discovering its chambers.

The northern stone Pyramid has its exterior casing, the lining of its passages, and chambers of a white compact limestone, which was brought along the two causeways from the quarries, lying in a westerly direction, or by two others which conduct to the Nile, where the stone might have been brought from the opposite side of the river.

The original base measured 719 feet 5 inches, its perpendicular height 342 feet 7 inches, and the angle of its casing 43° 36′ 11″.

The top was formed of one block of Arabian stone, which rested upon a course formed of four others, 4 feet 9 inches in thickness: those immediately below averaged 2 feet in thickness, and near the bottom 3 feet, and were all laid in regular horizontal courses,

and well built. The entrance has its centre 12 feet 6 inches to the eastward of the centre of the northern front, and the bottom of it is 94 feet, higher than the base of the building.

The passage is 3 feet 6 inches wide, 4 feet high, and inclines at an angle of 27° 56′. Its original length was 205 feet 6 inches: the lower portion, and a horizontal passage, 24 feet 4 inches long, leads to the first chamber, which is 27 feet 6 inches in length from north to south, and 12 feet from east to west, having its floor level with the base of the pyramid. The four lower courses of the walls, to the height of 11 feet 8½ inches, are perpendicular; over these are eleven other courses, each of which overhangs the other nearly 6 inches; so that the ceiling is only 14 inches in width: the two first courses, which project, are each 3 feet in thickness, whilst the others are about 2 feet 6 inches: the height of this chamber is 40 feet 4 inches.

From the south-western corner of this chamber is a passage 10 feet 4 inches long, 3 feet 6 inches wide, and 4 feet 6 inches high, which leads to another similar chamber, at the end of which, at the height of 25 feet 3 inches from the floor, is a passage running southward, 24 feet in length, to another chamber, 27 feet 3 inches long from east to west, and 13 feet 7 inches in breadth: the sides are perpendicular to the height of 12 feet, after which there are fourteen courses overhanging each other; its total height being 48 feet.

Southern stone Pyramid is singular, from its having two inclinations: the mass or body is formed of stone, and its casing appears to have been brought from the quarries of Mokattam.

Its base measured 616 feet 8 inches, and its total present height is 320 feet.

The angle of the casing of the lower portion is 54° 14′ 46″, and that of the upper 42° 59′ 26″, the platform at the top being about 40 feet square.

There are two inclined passages: one has its entrance in the centre of the northern front, about 35 feet perpendicularly above the base; the other at 44 feet, to the southward of the centre of the western front, at a perpendicular height of 97 feet 8 inches above the base.

The entrance from the western front of the pyramid was by a passage 222 feet 8 inches long, and 3 feet 4 inches wide and high. At the end was a horizontal passage, 65 feet 6 inches in length, and in it were two portcullises: these were slipped down inclined planes

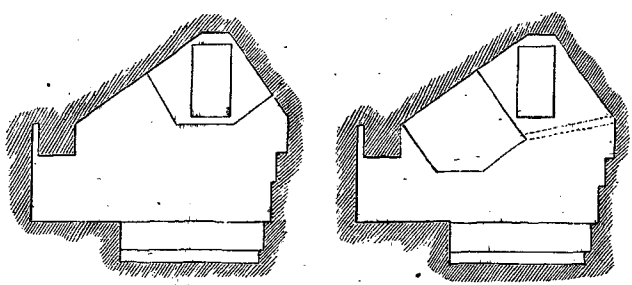


Fig. 39. DASHOOR.

into their position to cover the opening of the passage: at the eastern end of the horizontal passage was a chamber, 21 feet 6 inches long, 13 feet 6 inches wide, and 52 feet 6 inches high.

This pyramid was the only one that had its inclined passage from any other quarter than the north.

Small Pyramid was built of roughly hewn blocks, and was cased with Mokattam stone. Its base measured 181 feet, and its height 106 feet 9 inches; the angle of its casing being 50° 11′ 41″.

Southern brick Pyramid. The bricks contain a quantity of straw, pieces of broken pottery and stone, and vary in size; they are in length from 13½ to 15½ inches, and in thickness from 3½ to 7¾ inches.

This pyramid had been cased with stone from the Mokattam quarries: its original base measured 342 feet 6 inches; and its height, perpendicularly, 267 feet 4 inches, the angle of its casing being 57° 20′ 2″.

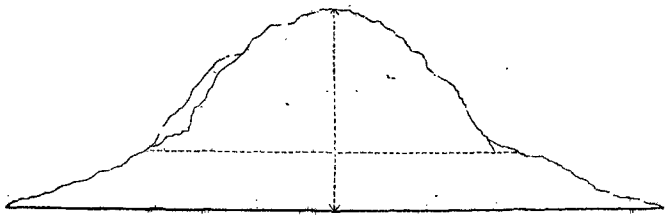
The interior of these brick pyramids has not been examined.

Pyramids of Lisht. The northern at the base now measures 360 feet, and the southern 450 feet.

Pyramid of Meydoom has a base 530 feet square: it is built in three heights or degrees, forming so many truncated pyramids, the angle being 74° 10′. The lower degree measures at its base 199 feet, and is 69 feet 6 inches in height; the second is 127 feet, and 32 feet 6 inches high; the upper is about 22 feet 6 inches high.

The blocks are of a compact limestone, about 2 feet thick, laid at right angles, and well

put together; the whole being originally cased with others: it has not had its interior described.



Pyramid of Illahoon is built round a knoll of rock, which has been faced with crude brick; the body of the pyramid being formed of the same material, is supported by stone walls, which cross the pyramid at its two diagonals, and others proceeding out of them, running parallel with the sides. The bricks are laid in mortar, and measure 16½ inches by 8½ inches, and are 5 inches or more in thickness: they are formed of Nile earth and chopped straw The outer casing was of stone, and the present base measures 360 feet, and height 130 feet.

The use of unburnt bricks was general throughout Egypt, and their manufacture gave employment to a great body of labourers; this simple material, in our own day, is often found more economical than stone, quarried or obtained upon the spot; gardens, and even inclosures to the temples of the gods, in Egypt, were often surrounded by walls of crude brick, merely baked in the sun. The demand being at one period so great for bricks, the government undertook to manufacture them, and to supply the public at a reasonable price; to do this in a manner to improve the revenue, the seal of the king or his authorised agent was stamped upon them, and all persons forbidden to engage in the manufacture.

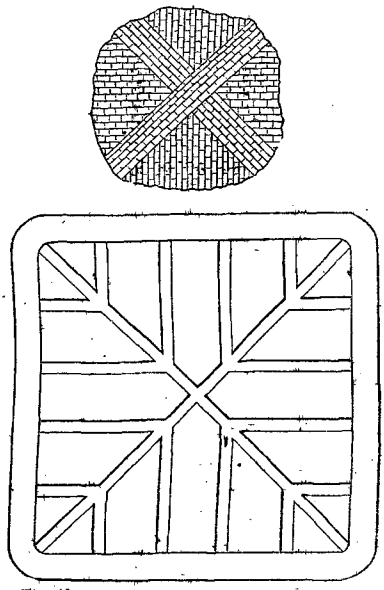


Fig. 40. ILLAHOON.

Pyramid of Howara is constructed of crude bricks, containing chopped straw: they measure 17½ inches by 8¾, and are 5½ inches thick, laid on a fine gravel: originally it was cased with stone. Its present base measures 300 feet, and its height 106 feet.

Southward of this pyramid are the ruins of an extensive labyrinth, as it is supposed.

Pyramids of Biahhmoo are five miles from Medeenet el Faioum: they consist of two masses, about 30 feet by 22, and about 30 feet in height.

Pyramid of El Koofa, in latitude 25° 10′, has its present base 59 feet 6 inches square: there are 27 courses, built in three several degrees, 38 feet 6 inches in height above the rock.

Ethiopia.—The Island of Meroe, which is formed by the conflux of the Astapus and Astaboras, according to Diodorus Siculus is in length 375 miles, and in width 125. It is situated between the twelfth and eighteenth degrees of north latitude, and was long the seat of empire of the kings of Ethiopia.

The Pyramids at Meroe, which at this day remain, are above 80 in number, and some of them contain hieroglyphics and sculpture of no ordinary kind: they are all constructed of red sandstone, from quarries in the neighbouring hills, which lie to the east of them: the stone is of a soft quality, and of a brownish red tint, and the blocks, which are 2 feet 6 inches long, are laid in regular courses, a foot high.

These pyramids vary in dimension from 20 feet square to 63, and their height is about the same as the length of their base; at the angles of some, instead of an arris, or sharp edge, is a bold bead, and in many, at about 12 or 14 feet from the top, is a small window. But the most singular part of their arrangement is that of having on their east sides a portico

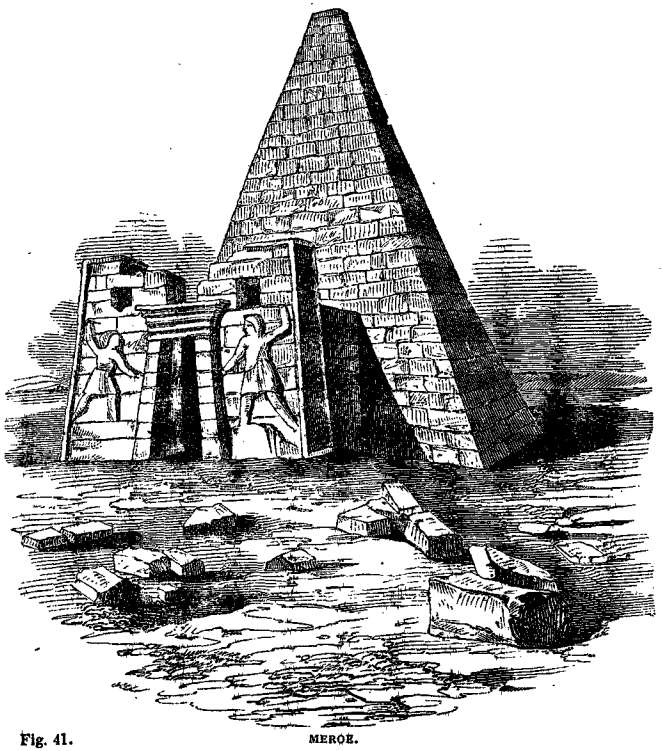


Fig. 41. MEROE.

which contains a room varying in width from 11 feet 6 inches to 12 feet 6 inches; and in some instances there are two rooms.

The height of these porches in some instances are 18 or 19 feet, and they bear, with their doorway, 3 feet wide, a strong resemblance to the Egyptian propylon.

Above the doorway is an architrave, over which is a square fillet, and then a bold carved cornice, ornamented with a winged globe.

One of the best proportioned of these propylons or entrances has the doorway 11 feet 6 inches high, and to the top of the cornice, 14 feet. On each side the wall slightly battered. At the bottom they measure 7 feet 6 inches in width, and at the top 7 feet.

These porticoes do not much vary in dimensions, although the pyramids to which they are applied differ.

These pyramids do not appear to contain any passages or rooms, and they are all probably constructed over wells, in which the dead were deposited.

One of the porches is arched, and consists of four or five stones constructed in a regular manner, said to be of the highest antiquity. It is stated to be the earliest known,

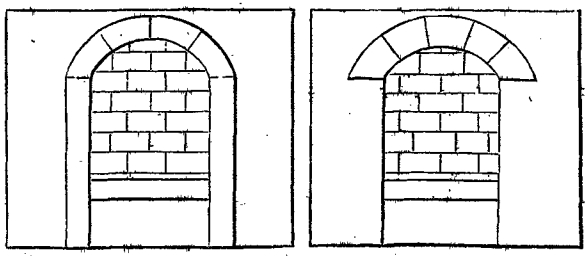


Fig. 42. MEROE.

and that in all probability the Egyptians derived their knowledge of this kind of construction from the Ethiopians. Diodorus Siculus informs us that it was from them the Egyptians learned to honour their kings as gods, to bury their dead with so much pomp, and also that from them they received their instruction in sculpture as well as in hieroglyphical representations; that the Egyptians were a colony drawn out by Osiris, after Egypt was formed by the deposit of the Nile; that the Egyptian laws were the same as those of Ethiopia, &c. — Lib. iii. cap. 1.

At Gibel el Berkel, three and a half miles east of the small town of Meroe, and about 5200 feet from the Nile, are several remains, among which are those of a fine temple, said to have been built by Tirhakah, who was the Ethiopian king that assisted Hezekiah

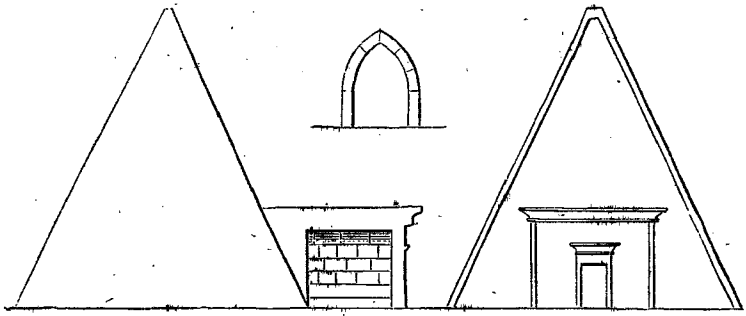


Fig. 43. GIBEL EL BIRKEL.

when he was at war with Sennacherib, king of Assyria. These several temples are of considerable dimensions, and agree in their architecture and sculpture with what is found in Egypt.

On the western side of the mountain, from whence the stone was taken for the building of these several temples, remain seventeen pyramids, which were the burial-places of a dynasty of unknown kings: they resemble those of Meroe. They vary in height from 35 to 60 feet, and usually consist of from 30 to 60 steps, which recede about 6 inches, so that they form convenient means to mount to the top.

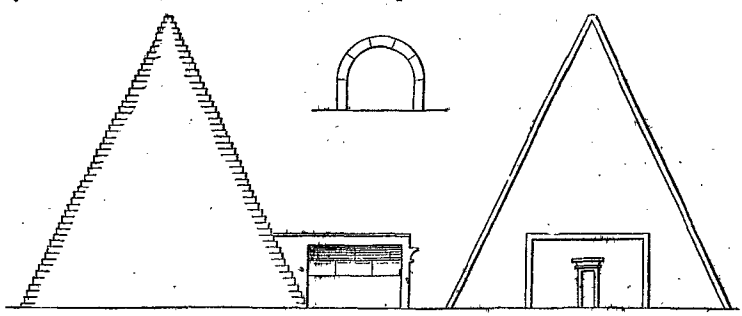


Fig. 44. GIBEL EL BIRKEL.

Pyramids of Nouri. There are traces of thirty-five, fifteen of which are in tolerable preservation. They vary in dimension from 20 to 110 feet square. Eight of them are 80 feet square, and four 70; their height is usually as much as the length of their side. The largest is built up in three stages, and the interior of most of them seem composed of a conglomerate, or puddingstone, and the casing generally of soft sandstone.

The pyramidal form seems to have been generally adopted by the Egyptians and Ethiopians, who considered their palaces only as inns where they tarried for a day, but made their sepulchres habitations of rest for ages: there are no such remains in Greece; yet we find them in Etruria. According to Pliny, the Etruscans built the tomb of Porsenna in this form, or rather it had five small pyramids. At Rome, the monument of Caius Cestius is pyramidal, and constructed of marble: its base measures 96 feet, and height 121 feet. Caius Cestius, who is supposed to have died when Agrippa was consul, was descended from a noble family, and appointed one of the epulones to prepare the banquets for the gods, at

the ceremonies of the lectisternium, so frequently mentioned by Livy the historian. From the peculiar form of this monument, and its being the only one at Rome of the kind, we should almost fancy that it had been derived from some of those in Nubia, with which it so exactly corresponds in arrangement and dimension. Had Caius Cestius held office under the Roman general Petronius, in his expedition against Queen Candace, when he penetrated into Ethiopia, and took the towns of Pselchis, Premmis, and Napata, about twenty years before the birth of Christ, we should have supposed that he had been struck with the respect paid to the dead in some of their necropoli, and selected the same form for his own place of sepulture. In the interesting

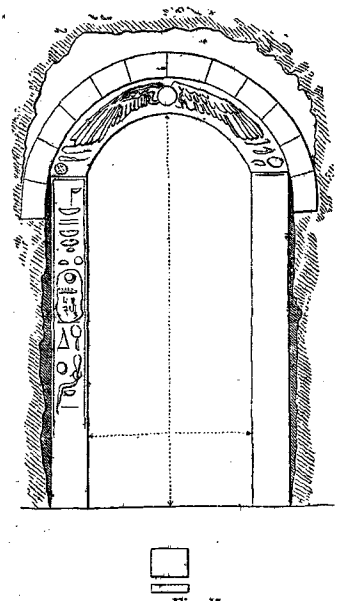


Fig. 45.

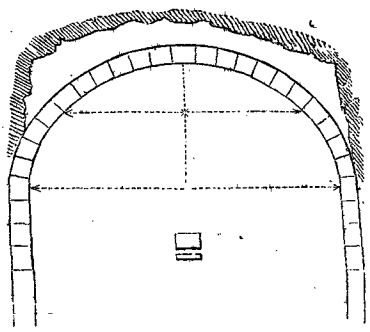


Fig. 46.

travels of G. A. Hoskins into Ethiopia, is the description of an elliptical brick arch (*fig.* 46.), which he discovered in a tomb at Thebes, situated near the valley of the sepulchre of the queens. The roof or ceiling was painted upon a plaster ground, and along the centre was a line of hieroglyphics, which contained the name of Amunoph I., which proves the existence of the arch in that part of Egypt fifteen centuries and a half before the Christian era. Its span is 8 feet 6, and its rise 3 feet 4 inches.

Another brick arch is also described on the road from the Memnonium to the valley of the Hassaseef, in a small tomb, which is also vaulted.

This has a lower arch of brick resting on a shelf cut on each side of the native rock: the access to this tomb is through a hole in the ceiling from the floor of another tomb above it, where the construction of the arch is seen. The whole is covered with plaster, and on the jambs of the recess are inscribed the titles and prænomen of Thothmes III., Sun, Establisher of the World, fifth king of the eighteenth dynasty, who reigned fifteen centuries before Christ.

In the pyramid at Gibel el Berkel is a semicircular arch, the key-stone of which is 1 foot 9 inches in length.

The only stone arch said by Mr. Hoskins to be met with in Egypt is at North Der, at Thebes. The vaulted tomb at Memphis is of the time of Psammeticus, who reigned immediately after the Ethiopian dynasty; and it is inferred that the Egyptians learned the use of the arch from the Ethiopians.

Alexandria. — This ancient port was improved by Alexander the Great, after his success against Tyre, and, according to the historian Gibbon, the undertaking was as noble as any ever executed by the son of Philip. Having journeyed through Egypt, and observed the highly productive state of the country, and that it was watered by one of the largest rivers of the world, which discharged itself by seven mouths into the Mediterranean Sea, he imagined that its only want was a convenient haven. Pelusium, at the eastern mouth of the Nile, was not capable of improvement. Canopus, on the eastern side of the western mouth, was still more inconvenient, although it had a landing-place for ships.

Alexander, who was liberal and magnificent, found among his countrymen engineers qualified to second his bold ideas, and he had, what is a rare quality among princes, the talent to select the best fitted to execute them. On this occasion he appointed Dinocrates his architect and engineer, who had already acquired great celebrity in the construction of the temple at Ephesus, dedicated to Diana.

The site selected for the new city was on the western side of the Nile, between the river and the lake Mareotis,—for which nature had done much, and which seemed capable of being made by art all that was desirable; and an opportunity was afforded to humble the Tyrians, to divert that commerce which they had long enjoyed; to change the current of the Indian trade by Suez, the Nile, and its canal, to the new city of Alexandria.

In the midst of the capacious bay on the shores of which the city was marked out, and at some distance from the mainland, lay the island of Pharos, which acted as a natural breakwater, and which, in the time of Strabo, was of an oblong form; this Dinocrates united with the mainland by an extensive causeway, or earth wall, and, from its length being 7 stadia, it was called the heptastadium. This grand terrace divided the bay into two harbours, which communicated with each other by means of two openings left for vessels to pass from one to the other.

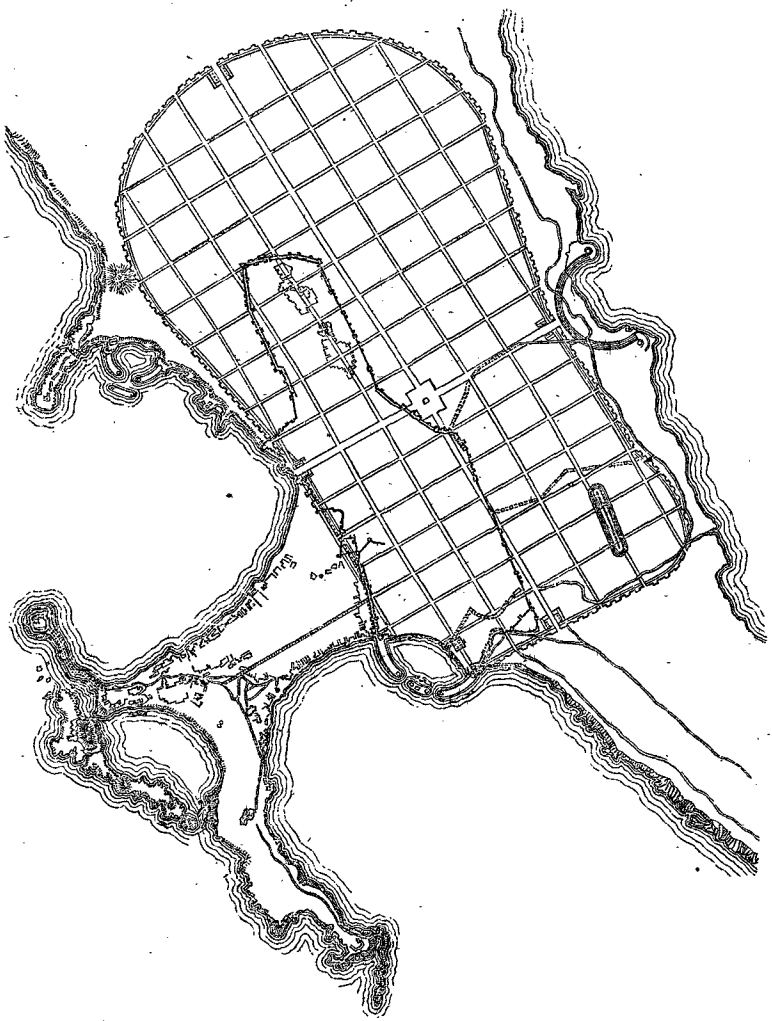


Fig. 47 ALEXANDRIA.

The city was marked out with great regularity: its form was that of a Macedonian mantle or cloak, and three hundred and twenty years before Christ the walls were con-

siderably advanced. All the streets were set out at right angles with each other, and more than a third of the area comprised within the walls was devoted to public purposes.

Every private dwelling had its reservoir of water provided for it, which was supplied by subterranean conduits from the Nile; all built of stone, with flat terraces at the top, which answered for their covering, timber being sparingly used in the construction. The cisterns and conduits were lined with a fine cement, which remains perfect at the present day.

To render the harbour approachable at all times, a lighthouse was built on a rock some distance from the eastern extremity of the Isle of Pharos, which was long considered one of the wonders of the world, and which has given a name to all others. A mole united the rock with the mainland, and Sostratus of Cnidos, who was so esteemed by Ptolemy Philadelphus that he was surnamed the friend of kings, was the engineer employed for its construction. This pharos was in height 450 feet, and could be seen at a distance of 100 miles. It was formed of several stories, decreasing in dimension towards the top, where fires were lighted in a species of lantern. The ground-floor was hexagonal; the sides alternately concave and convex; each a stadium in length; the second and third stories were of the same form; the fourth was square, with a round tower at each angle; and the fifth circular, continued to the top, to which a winding staircase conducted.

The whole, exquisitely wrought in stone, was surrounded entirely by a sea-wall: on entering the harbour, this wonderful structure was on the right hand, and the promontory of Lochias to the left, where was placed the palace or royal residence, near which was the island, called Antirhodus, which contained a small harbour, devoted entirely to the reception of the royal vessels. The ancient causeway now forms the site of part of the modern town, and is in length about 4000 feet; on the easternmost side is the great harbour, and on the western that of Eunostus, or, as it is now called, the ancient port. Here is a basin or kibotus, which by means of a canal communicates with the Lake Mareotis, the dimensions of which Strabo says were 300 stadia in length, 100 in breadth, and that it contained 8 islands.

Alexandria was second in importance only to Rome itself: its circumference was 15 miles, and its population estimated at 300,000 free inhabitants, besides an equal number of slaves and dependents. In its streets idleness was unknown: some were employed in blowing glass, in weaving linen, and manufacturing papyrus.

When Cæsar arrived at Alexandria, he sent to Rhodes, Syria, and Cilicia for his fleet; and upon reconnoitring the town, he found all the avenues and passes shut up by a triple wall, 40 feet in height, built of squared stone. The lower portions of the city were defended by lofty towers, ten stories in height. There were many timber structures of the same height, movable on wheels, which could be drawn by horses. We also learn that he found Alexandria almost hollow underneath, from the many aqueducts that furnished the private houses with water from the Nile, where, being received into cisterns, it was allowed to throw down the earthy matter, and become perfectly clear. Ganymed, the Alexandrian general, to deprive the Romans of a supply in that part of the city of which they had taken possession, stopped the current through these subterraneous passages which led from the Nile, and turned salt-water into them, which caused great wonder as well as inconvenience to the Romans. Cæsar, on the discovery, ordered his soldiers to find water by digging wells, telling them that on all sea-coasts fresh springs abounded; and the alacrity used was so great, that they arrived at fresh water in abundance the first night after the digging commenced.

Smelting and refining metals. The Egyptians began this process by pounding their golden ore, and reducing it to very small grains; they then put it into a mill, and ground it to powder; after which it was spread on boards slightly inclined: water was then made to flow over it, which carried away the earthy particles. After the watering had been frequently repeated, it was rubbed by the workmen for some time between their hands, and wiped with small sponges, until nothing was left but the gold. It was then put into earthen pots, and mixed with certain proportions of lead, salt, tin, and barley meal: after this it was poured into other vessels, which were luted with great care and placed in a refining furnace for five days and nights; these were then taken out and suffered to cool, when the gold was found to be quite pure. They do not appear, according to Pliny, to have used quicksilver, for the refining of either gold or silver: lead was the menstruum, and by frequent meltings the pure metal was obtained. The great quantity of gold used by this people convinces us that the art of mining, smelting, and refining that metal was well understood.

Forging metals was known in Egypt at the earliest time; most of the arms, tools for husbandry and the mechanical arts, were usually made of copper or brass, though in the time of Moses we find iron well known. He describes its hardness, speaks of mines, and mentions the iron furnaces, and tools for cutting stone, made of iron.

Hydraulics. In the school of Alexandria, which flourished under the patronage of the

Ptolemies, the first machines for the purpose of raising water seem to have been invented. After Hippocrates had constructed tables which showed the exact motion of the sun, Clepsydræ, or water-dials, were brought to great perfection by Scipio Nasica, the cousin of Scipio Africanus, who about two hundred years before Christ introduced them into Rome.

Ctesibius, who flourished in the reign of Ptolemy Physcus, an hundred and twenty years before Christ, brought these machines into very general use, and invented the hydraulic organ, which was operated upon by air and water. In the clepsydra he introduced, probably for the first time, toothed wheels: this instrument for the measurement of the hours was a cylinder resting upon a pedestal; two figures were placed upon the latter, one of which dropped water from its eyes, whilst the other pointed with a wand to the hour marked on a vertical line drawn upon the cylinder. This cylinder turned on its axis once a year, and on it were drawn curved lines, which exhibited the inequality of the hours on different days, by their being marked at unequal distances.

The manner of working this machine was to allow the water to rise through a tube, which, passing through one figure, was discharged by the eyes, into a reservoir, M, from which it passes by a hole near *m*, into the pipe B, C, D. In this pipe a piece of wood

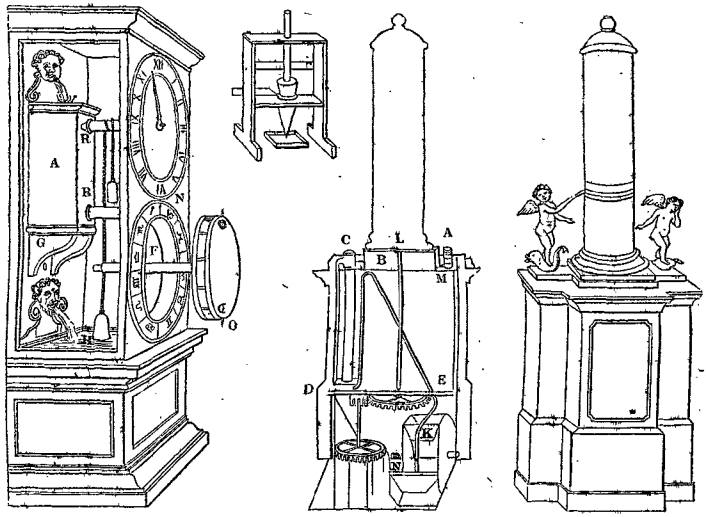


Fig. 48.

floated upon the surface, and by its ascent, as the pipe filled, it raised the small pillar C, D, on which the other figure rested, and as the float rose in the pipe the wand was made to point to the different hours. Every twenty-four hours the vessel became filled, as did the inverted siphon, which communicated with it. The water was then drawn off by the siphon, and falling in its descent into the buckets of the wheel below, put that into motion. This wheel had six buckets, and therefore made one revolution every six days. Its axis carried a pinion of six teeth, working on another wheel of sixty teeth: this also carried another pinion of ten teeth, and drove a wheel of sixty-one teeth, which by its axis turned the pillar once round in 366 days.

These machines indicate considerable hydrodynamical knowledge, and derive their origin from the previous discoveries of Archimedes.

Another clepsydra received the water in a reservoir, which was always kept full, and descended by a pipe into a hole formed in the great drum. This hole corresponded to one of the openings in the groove round the circumference of the small drum. The apertures of the groove in the small drum were of different sizes, to admit different quantities of water, according to the length of the day; and the proper aperture for the given day was found by placing the index opposite the sun's place on the zodiac, shown at N, the index O being used for the night hours. The water which descended through the openings in the small drum was conveyed by the pipe F, through the aperture at G into the reservoir H. As the water rose in the reservoir, the inverted vessel, suspended by a chain, which passed round the axis R, and balanced by the counterweight, ascended and moved the hour hand, which pointed to the dial plate.

Hero, the disciple of Ctesibius, wrote a treatise on mechanics, wherein was described at length the various mechanical powers, which were all reduced to the lever; he left also another work, called Spiritalia, in which is an account of the forcing pump, which raises water by the elasticity of the air, and was probably suggested by the Egyptian noria, a contrivance in which a number of earthen pots were attached to the periphery of a wheel for the same purpose.

The Great Wall of crude brick, built by Sesostris, on the east side of Egypt, to defend it against the irruptions of the Syrians and Arabians, extended from Pelusium along the edge of the desert by Heliopolis, for 1500 stadia, or about 187 Roman miles.

Amasis, who was a great promoter of the arts, erected at Sais a magnificent propylæum, in honour of Minerva, where stones of prodigious magnitude were used in the construction; Herodotus says these stones, of amazing thickness, were brought from the quarries of Memphis, and part from the city of Elephantine, which is distant from Sais a twenty-five days' journey; but that, in his opinion, the work most to be admired was an edifice which Amasis brought from Elephantine, constructed of one entire stone. To transport this, 2000 men, all of whom were selected from the sailors, were employed for a period of three years. The length of this structure on the outside was 21 cubits, its width 14, and its height 8. Its length inside was 22 cubits and 20 digits, 12 cubits wide, and 5 high. It was placed at the entrance of the temple, and the reason assigned for its being carried no further was, that the architect, in consequence of his continual fatigue, was heard to sigh by Amasis, who, construing it into an evil omen, obliged them to desist. Some affirm, however, that one of those employed to move it by levers was crushed, for which reason it was moved no further. This resembled probably the red granite monolith at Tel-et-mai, which measures in height 21 feet 9 inches, 13 feet in breadth, and 11 feet 7 inches in depth, outside; and 10 feet 9 inches, 8 feet, and 8 feet 3 inches, inside.

At Memphis, a colossal recumbent figure, 75 feet long, was, according to Strabo, placed before the dromos of the temple by this king, as were also masses of granite, 20 feet in height. At Thebes and other places, as well as the quarries at Syene, are numerous inscriptions, which indicate the removal of granite blocks of enormous weight, for the decoration of edifices raised by this prince.

Quarries in Egypt. The granite was obtained from Syene, which is a district reaching from the island of Philæ, along the whole line of the cataracts; that of the finest quality is obtained on the banks of the river.

The beautiful pink or rose-coloured granite, the syenite of the ancients, is very hard, and composed of large crystals, which receive an excellent polish. Two thirds of the mass is rose-coloured feldspath; sparkling mica and glassy quartz fill up the intermediate spaces, mixed with hornblende occasionally. Pliny sometimes designates obelisks made of this granite as Thebaicus lapis, because it came from the region between Thebes and Syene.

Another granite, more resembling that of the ordinary kind, is found contiguous to it, with particles occasionally much coarser or finer. To these may be added, the fine-grained granite; the grey, with grey-coloured feldspath; black and white granite, which has white feldspath with black flakes of mica, and oriental basalt; and a very dark kind, which is owing to the abundance of mica.

The sandstone quarries of Hadjar Selseleh furnished the chief part of the building stone for the temples: they are situated in the sandstone district, and, according to some, the stone resembles the grès de Fontainebleau. When first taken from the quarry it is easily worked, and may be obtained in lengths of 30 feet or more.

We find stone quarries of great extent on the borders of the valley of the Nile. Limestone was generally employed in all the early buildings; and quarries, from whence large quantities were taken, may be seen at Masarah, where there are tablets remaining, cut in the time of Ames or Amasis, the leader of the eighteenth dynasty, who ascended the throne about 1500 years before Christ; and from these quarries all the compact magnesian limestone used in the construction of the pyramids of Gizeh was taken. There are other quarries at Téhneh, on the point of a hill, where is a thin deposit of crystallized carbonate of lime; numerous nautili are found imbedded in the limestone, some of which are more than 6 inches in diameter.

In examining these excavations, we obtain some knowledge of the early Egyptian practice of detaching masses of stone, and also a valuable lesson on the saving of both material and labour. To the Egyptians the difficulty of onstructing a pyramid was scarcely more than the removal of stone from the quarry, and building it up in the manner in which it lay previous to its being detached from the original bed; the only difference was, that the top stones of the quarry became the foundation stones of the pyramid: they were taken away in layers, all of the same thickness, and built in courses; and as the work proceeded, the quarry might represent as many steps from bottom to top as the pyramid. The stone was sure to lie the right way of its bed; and it would be scarcely necessary to mark an oblong stone, after it was detached; its depth being uniform with the others, would indicate sufficiently its true position.

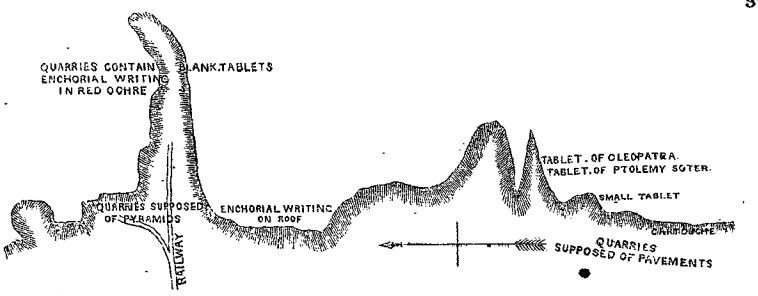


Fig. 49. MASSARA QUARRIES.

The manner in which a quarry was worked is deserving of our attention. It was commenced by levelling the surface of the rock and marking out a square area of sufficient dimensions to afford the quantity of stone required; around this was cut a deep trench; at parallel distances, 7 or 8 feet apart, according to the size of the stones, other parallel trenches were made, and then similar lines at right angles, dividing the whole into as many squares. After this the blocks were cut to their required thickness: layer after layer was thus removed, according to the depth of the quarry, or as long as it yielded good stone.

At other times, after the square was marked out on the top of the intended quarry, which was usually selected on the side of a hill, or where its face was perpendicular to the plain below, an horizontal trench was driven through the middle of the square, and then the masses of rock were detached on each side of this first groove; and as each layer was removed, new trenches were cut, until the whole assumed the character of a series of steps on each side of the centre, which rose from the bottom to the top of the quarry, resembling the form of a pyramid. The same machinery which lifted the stones from their beds or steps answered to elevate them to their new position.

Limestone continued in use for many years, after which a fine sandstone was employed, which was discovered to be of far greater durability. The quarries of Silsilis are extensive, and situated between Edfoo and Gébel Silsileh. From them most of the sandstone was obtained which was used in the Egyptian temples and other public buildings.

Tourah and Massara Stone Quarries — The Troici Lapidis Mons. The Pasha has here a railroad for conveying stone to the river, which is then transported to Cairo, a distance of between six and seven miles. These quarries supplied the stone to many of the pyramids and temples, and afforded employment to a vast number of men. On a range of sand hills, on the edge of the Desert, which extends the whole length of the quarries, was discovered upwards of 150 sarcophagi, made of compact limestone, which no doubt contained the bodies of those employed in extracting the stone. One sarcophagus was formed of earthenware in a single piece, having a lid of the same material. Many skeletons without coffins or sarcophagi were also found: these bodies appear to have been interred in their clothes, or wrappers of coarse woollen cloth. There were also heads of oxen, with the horns, and several hundred coffins, and many tombs covered with slabs of calcareous stone, where the bodies were preserved in bitumen, and the coffin not made use of. Among the several articles within them was the model of a pyramid in calcareous stone, 26½ inches square at the base, and of the same height; also two pieces of bronze, which resembled the heads of hatchets. There were several inscriptions to the local divinities, put up when fresh work was commenced in the quarries, the earliest supposed to refer to the reign of Amonemhe IV.: another to the time of Necho.

At the Tourah quarry is a tablet, dedicated to the Son of the Sun, Amonemhe, beloved of Phtah, the rampart of the south, and of Anubis: the opening of the quarries is also alluded to, and orders given for the cutting the good and white stone, which is calcareous, for the temples of the gods. Some of the tablets are in the form of a propylæon, having the hieroglyphic inscription on the lintels: one refers to Amenophis II., and has been interpreted as commanding the opening of the quarries to draw the good and white stone for the repairs of the temples for a series of years; the whole apparently being under the direct superintendence of a military chief, "attached to the heart of the king, for his knowledge and skill in architecture, one who had adorned the temples in Mesopotamia and in Libya, and was put over the *Bearers* of Egypt, of all the gods of the north and of the south." Libya and Mesopotamia are said by M. Champollion to have been conquered by Amenoph II., or by his predecessors. These tablets are signed by the royal scribe, Saph, the architect or surveyor engaged to design the public buildings.

Another of these tablets refers to Amenoph III., or Memnon, who is seen offering a symbolic eye in a basket which he holds in both hands. In the hieroglyphic inscription, he is

termed, the "Establisher of the Houses of Stone;" and he orders the opening of the quarries to procure good and white stone.

In the Massara quarries, which were worked from north to south, are tablets referring to Amasis, Psammeticus II., and to some of the Ptolemies. Beneath one of the hieroglyphic inscriptions of Amasis and his wife Nofreareh, is represented a block of stone drawn by six oxen on a sledge, attended by three men: and the interpretation of the writing is, that the quarries were opened in the forty-third year of Amonemhe, were again worked in the twenty-second of Amasis, when the temples of Phtah, and of Amon in Thebes, were built, the kings of the sixteenth and seventeenth dynasties at that time having their capital at Abydos. These tablets allude also to Thebes, which superseded Memphis as the capital after the kings of Egypt had grown more powerful. There are other tablets of the time of Ptolemy Philadelphus. The quarries at Silsilis are of vast extent, and masses of any dimensions might be hewn from them. When a quarry was opened, if the stone could not be drawn from the perpendicular face, they drove a horizontal shaft into it, at the level which would afford them the quality they required. They then worked the masses in horizontal steps, which they made of the necessary depth and width, and in quarries of considerable extent they left pillars at intervals to support the superincumbent earth. The stone, after it was quarried, was placed on sledges, and drawn by men or by oxen. Inclined planes were often used to facilitate its movement. Many instances may be found of a private mark on the stones, which indicated the number, drawn by the slaves employed for this purpose.

In a grotto between Antinoë and El Bersheh is a painting, where a colossal statue is moved by a number of men dragging ropes. This painting is a very early production, and shows the method employed at that time for moving great masses. 172 men, in four rows of forty-three each, pull the ropes attached to the front of the sledge, on which the statue, a seated figure, is placed. On the knees of the figure stands a man, directing them to move together, and to pull uniformly. The statue is secured to the wooden sledge by ropes: these are doubled, and further tightened by the insertion of long pegs, which were twisted round, and made perfectly secure. Some of the obelisks, brought from the quarries of Syene to Thebes and Heliopolis, a distance of 800 miles, are of a single stone, varying in size from 70 to 98 feet in length, and one of the largest at the great temple at Karnack has been calculated to weigh upwards of 297 tons, and must have been brought about 138 miles.

In the plain of Qoorneh there are two colossi of Amunoph III., each of a single block, and 47 feet in height, containing 11,500 cubic feet. At the Memnonium is another of Remeses II., which, when entire, weighed 887 tons, and which, from the nature of the stone, was probably brought 138 miles.

The shrine of the goddess Latona, at the Sebennitic mouth of the Nile, in the large city of Butos, astonished Herodotus, who says that it was 40 cubits or 60 feet in height, breadth, and thickness, and was cut out of one single stone: after it was hollowed out a stone 4 cubits in thickness formed its roof. The internal dimensions, or the thickness of the walls, are not given; but if of granite, as those monolithic temples were, the weight must have been some thousands of tons.

Obelisks, in their removal, required skill and strength; but to elevate them, considerable knowledge of mechanics must have been brought into application. They are often raised to a great height, and placed, with the utmost precision, in a perfectly perpendicular position. Some very large blocks of sandstone, and particularly one which forms the lintel to the gateway leading to the grand hall at Karnack, is 5 feet two inches square, and 40 feet 10 inches in length; and it seems difficult to understand by what means it was lifted to its present position; but the Egyptians were learned in the mechanical arts, and were evidently as capable of raising weights as we are at the present day. In one of the quarries at Syene there remains a broken obelisk, where it was separated from the rock, and the depth of the quarry is so small, and the entrance so narrow, that the stone could not be turned round; it must have been lifted up from its bed, as was the case with all the shafts hewn out of this quarry.

One of these obelisks, 99 feet in height, and on which 20,000 workmen were employed, was raised by Rameses. Pliny mentions the method usually adopted to float these masses from the quarries down the river. Two flat-bottomed boats were lashed together, side by side, and then had a trench cut for them into the Nile. They were laden at first with as much ballast as equalled the weight of the obelisk to be transported; when they were introduced under the weight, the ballast was taken out, and the boats rising as they were lightened, bore the obelisk in lieu of it.

These large masses of granite may have been detached from their beds in the same manner as is still practised in the East, where, after cutting a groove in the stone throughout the entire length, a fire is made upon the rock, which, when sufficiently heated, the burning ashes are swept suddenly off, and water as cold as it can be obtained is then poured simultaneously by a number of individuals into the groove, and a clean fracture takes place throughout the whole line.

Another method was, after the groove had been cut, to bore on the line small perpendicular holes, 18 inches or 2 feet apart, into which were introduced as many chisels: these were beat from one end of the line to the other by a number of men for two or three days together, when the mass detached itself with a clean fracture, and ropes were afterwards used to remove the piece so detached.

Metal wedges were sometimes applied to separate large blocks from the quarries, which were struck simultaneously throughout the line of the intended fracture; and often wooden wedges in a dry state were introduced into holes made to receive them, when they were saturated with water, and by their expansion a force was obtained which split off the granite.

Quarries of oriental alabaster are found in the Desert, where, at a latitude of about 28° 40′, the mountains which continue to Abyssinia are formed of Egyptian porphyry, various granites, serpentines, and other primitive rocks; but in the valleys running into the Wadee Moathil, the oriental alabaster is found among the mountains composed of limestone.

In the division of Ababdeh they obtained the green breschia, slate, micacious, taliose, and other schists. Near the coast, a short distance from the sea, is another ridge of limestone hills, among which rises Ghareb, a lofty peak of granite, the summit of which is 6000 feet above the level of the sea.

The porphyry quarries that supplied Rome are twenty-seven miles from the Red Sea, near Gebel e Dokhan, and about twenty-four miles to the south-east are the granite quarries which were worked in the time of Trajan.

Obelisks, or single blocks of stone. The largest are formed out of the red granite of Syene: they are at the base of a quadrilateral form, diminishing gradually to the top, which is finished by a small pyramid: their opposite sides are equal, but vary at times a few inches in dimension.

These obelisks in their original situation were placed in pairs, one on each side of the propyla, or entrance to the temple, or in front of the gateways.

At Alexandria are two of red granite, one of which, called Cleopatra's needle, is erect. They probably decorated the entrance of either a temple or a palace, as Pliny mentions that was their position. They are 65 feet in height, and about 8 feet wide at the base, and the weight of one has been calculated at 284 tons. They were of the time of Remeses the Great.

At Luxor, obelisks 80 feet in height are found, generally on the site of most of the ancient cities, lying on the ground. Such mark the position of Tanis, the Zoan of antiquity, and of Heliopolis: there are others at Medinet el Faioum, at Axum in Abyssinia, at Jebel Barkal in Arabia Petræa, and several other places.

At Arles in France there is an obelisk; and at Constantinople are several, of the granite of Syene.

Obelisks at Rome. Most, and perhaps the whole, of the twelve were taken from Egypt by Augustus, or the emperors who immediately succeeded him. After having been thrown down by the enemies of the Imperial City, many of them were again mounted on pedestals, either by Popes Sixtus V. or Pius VI.

That of St. John Lateran is the most lofty, and the same erected in the Circus Maximus by the emperor Constantius. It was broken into three pieces, and before it could be again set up, it was necessary to cut off from the larger end between 2 and 3 feet, so that the length of the shaft is abridged of that quantity, and now only measures 105 feet 6 inches. The breadth of the sides is not equal, two being 9 feet 8 inches, and the others 9 feet only. The circumfence at the base is 37 feet 6 inches, and at the top 24 feet 10 inches.

Its solid contents have been estimated at 5960 cubic feet; and as it is composed of red Egyptian granite, its weight is about 440 tons, or a little more.

It is covered with figures, and originally stood at Heliopolis, from whence it was removed to Alexandria by the father of Constantius; from which place it was taken to Rome, on a vessel constructed for the express purpose, moved by 300 rowers; and Ammianus Marcellinus tells us that when it arrived at the banks of the Tiber it was passed through the gate of Ostia, and the *piscinam publicam*, on rollers. After its arrival at Rome a forest of timber was employed for a scaffolding, and by the aid of 1000 men and much tackle it was suspended in the air, and finally placed on its pedestal. This obelisk was again raised by Fontana, in the year 1588.

The Vatican obelisk, in front of St. Peter's, in the year 1586 was moved by Fontana, from the Vatican circus, where it had been placed by the Romans, and dedicated to Augustus and Tiberius. It is without hieroglyphics, and still entire, being 83 feet 2 inches in height, each side of the base 8 feet 10 inches, and at the top 5 feet 11 inches. According to Pliny, it was cut by Nuncoreus, the son of Sesostris, by Herodotus called Pheros, and who is said to have erected two obelisks, each 100 cubits in height.

Santa Maria Maggiore obelisk, broken into three or more pieces, is without hieroglyphics, and was erected in its present situation by Fontana. Its height is 48 feet 4 inches.

That of Flaminio del Popolo, re-erected by Fontana, is broken in three places, and has hieroglyphics. Its length is 78 feet 6 inches. It formerly stood in the Circus Maximus, and was one of the two erected there by Augustus. The sides are unequal: two are 7 feet 10

inches at bottom, and 4 feet 10 inches at the top; the others are 6 feet 11 inches, and 4 feet 1 inch.

That of Piazza Navona, or the Pamphilian obelisk, has some hieroglyphics, is 54 feet 8 inches in height, and has the name of the Emperor Domitian cut on it.

That of Minerveo della Minerva has hieroglyphics, and was placed by Bernini, in 1667, upon the back of an elephant. It is about 17 feet in height. This was found among the ruins of the Iseum, in the Campus Martius; its sides incline more than either of the other obelisks at Rome.

That of the Pantheon has hieroglyphics, and is 19 feet 8 inches in height: it was placed in its present situation in 1811.

Monte Cavallo, on the Quirinal, has no hieroglyphics, is 47 feet 8 inches in height, and was broken into two or three pieces.

Sallustiano della Trinita di Monte has hieroglyphics, and was placed in its present position in 1789: its height is 43 feet 6 inches; it has been much broken, and is joined together in an imperfect manner.

Monte Citorio. The height of this obelisk is 71 feet 6 inches, and was placed in its present position in the year 1792. Two sides at top measure 5 feet, the others 5 feet 1 inch, at the base 8 feet. It was found, broken into four pieces, among the rubbish on the Campus Martius, where it had been erected by C. Cæsar Augustus. Pliny tells us it was brought from Heliopolis, and was the work of Sesostris; but modern writers have assigned it to the time of Psammeticus II.

Monte Pincio has hieroglyphics, and is 30 feet in height.

Vella Mattei, on the Cœlian hill, is another small obelisk.

There were formerly many other obelisks at Rome, besides the twelve above mentioned. At Florence there are two, one very small, not more than 5 feet 10 inches high. In a work by Zoëga, "De Usu et Origine Obeliscorum," is an account of most of the obelisks known, with much valuable information.

Of the bridges of the Egyptians we have no account left us: occasionally we find a dyke passed by laying across it large stones one upon another, without any indication of an arch,

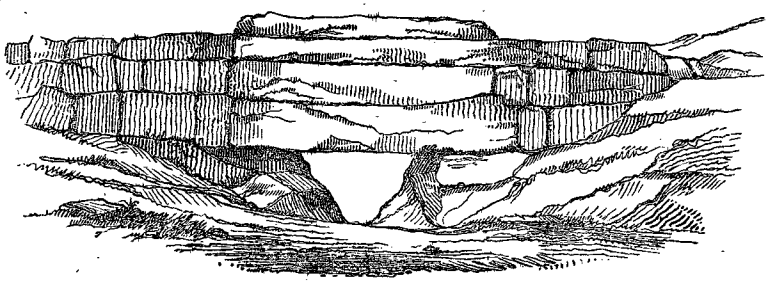


Fig. 50.

the stability depending upon the goodness of the material employed: in all probability the narrow streams and watercourses were passed by this simple means; and large rivers that could not be so forded had a ferry.

CHAP. III.

GRECIAN ENGINEERING.

Greece, though in its general aspect rugged, has a climate highly propitious; its mountains contain many valuable metals, and the finest marbles: this celebrated country is comprised between the thirty-sixth and forty-first degrees of N. latitude. Among its mountains are Olympus, Ossa, Pindus, Œta, Parnassus, Helicon, Cithæron, and Parnes. Every acropolis has its plain, fruitful in corn, wine, and oil; and the coast is surrounded by excellent harbours. Agriculture, by the refined Greeks, was left to the management of their slaves.

Although nature was so bountiful, and the Greeks possessed what might be called a maritime country, they were slow to use the advantages which their good harbours afforded, or to benefit from that commerce which the islands by which they were surrounded were likely to induce. Little progress was made by them in either navigation or commerce

till after Xerxes' expedition to the Peloponnesus. Athens and the other states then formed a navy, and the expedition of Alexander, when his ships sailed down the Indus, may be considered as the earliest instance of the Greeks navigating the ocean.

Corinth, Athens, and the smaller states, as Megara, Sicyon, Cos, Cnidus, and others, devoted themselves to the cultivation of commerce; but the fine arts always most particularly attracted their attention; and the vigour, chasteness, and grandeur they threw into their several designs, continue to call forth the admiration of the world.

The seas which surround the coasts of Greece are broken by headlands, islands, and lofty mountains, and are subject to sudden and violent storms. These, apparently adverse to improvements in the arts of navigation, were the cause of making the inhabitants excellent boatmen. The Greeks depended upon their oars, and seldom hoisted the sail; for where the seas were landlocked the stoutest vessels experienced the greatest danger: light vessels could not only creep along the coast, but could in sudden tempestuous weather seek refuge in shallow water, or upon an emergency be drawn, as at present, out of danger, on to the beach. The vessels were without decks, and anchors were unknown. When moored, it was usual to fasten them to some object on the shore; but they were generally hauled out of the water.

We cannot therefore expect to meet with any important engineering works on the borders of the Mediterranean. Capacious harbours, formed by nature, were resorted to by their numerous small craft, and many a retired nook amidst their lofty cliffs was made inaccessible by throwing a chain across its entrance, thus preventing any molestation from an enemy. Wherever their ancient towns are met with on the coast, we find the remains of jetties, causeways, and landing-places, and, in some instances, the foundations of the buildings which formed their arsenals. Some ancient pictures, which have been rescued from baths and tombs, as well as fragments of sculpture and coins, convey to us ideas of the form of their ships, and their method of protecting them when on shore.

Athens had three ports near each other,—the Piræus, Munychia, and Phalerum; and the first, whilst the city was in a flourishing state, was the emporium of all Greece: it was formed in a recess of the shore, and protected by a peninsula which extended into the sea. A rocky eminence called Munychia separated it from the other ports of Munychia and Phalerum, which indented the narrow isthmus on the eastern side. The city was twenty stadia distant from the sea at Phalerum; and from the Piræus forty stadia.

Phalerum was named after Phalerus, who accompanied Jason in the Argonautic expedition, and from it Theseus sailed when he set out for Crete, and Menestheus for

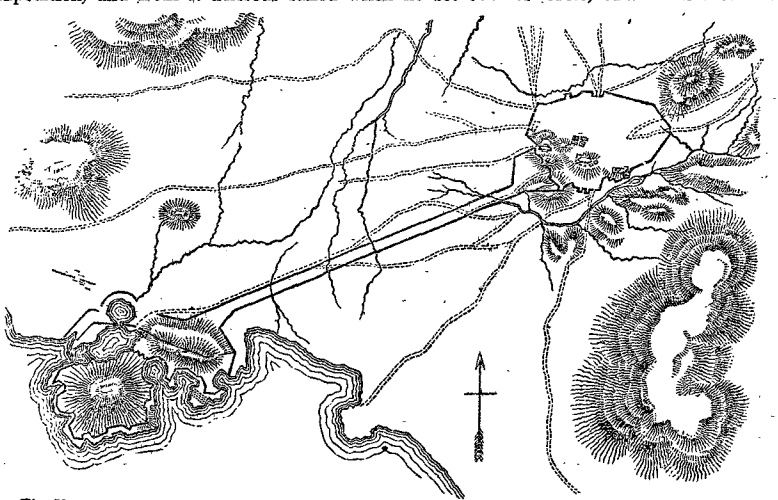


Fig. 51. PIRÆUS.

Troy: it continued to be the harbour of Athens until the time of Themistocles. The entrance is narrow; its form approaches the circle, and through its clear and transparent water is perceived a fine sandy bottom.

Munychia is of an oval form, and somewhat larger, having its entrance narrow.

The chief port was the Piræus, which had its entrance flanked by two rocky points, one belonging to the promontory of Eëtion, the other to that of Alcemus; within were three stations for shipping.

Themistocles recommended that this triple harbour should be given up, and the more

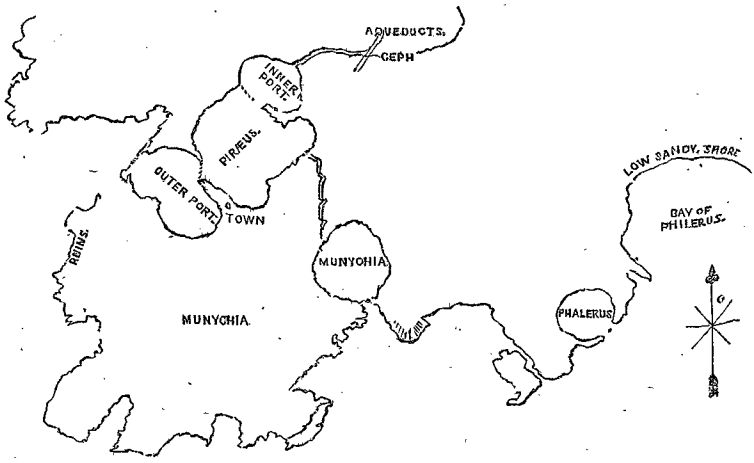


Fig. 52. THE THREE HARBOURS.

capacious, that of Phalerum, made use of: about 407 years before Christ the great wall was commenced by him, which was to serve for its protection; it was of hewn stone, put together without any cement, cramps of iron run with lead being used to the external courses, to hold them more firmly together. This wall, of a sufficient width to allow loaded carriages to pass each other, was 40 cubits high.

Hippodamus, to whom the city of Rhodes owed the great beauty of its structures, was employed, during the Peloponnesian war, in the construction of this port: he built five porticoes, which, uniting, formed the long portico — an agora or market; and also another, farther from the sea, called Hippodamia.

Adjoining the port were constructed dwellings for the mariners, a theatre, and temples for the use of all who resorted hither; so that the Piræus rivalled Athens itself. All the ground of Munychia where houses could be built was occupied by them.

About 330 years before Christ, Demetrius of Phaleres ordered Philon, the celebrated engineer, to enlarge the port of Piræus, to construct an arsenal sufficient to house all the arms and marine stores, and whatever was required to be preserved for the use of the city. He succeeded so well in carrying out the wishes of the people of Athens, and in giving an account to the public assembly of what he had performed, that they, pleased by his eloquence and happy mode of expression, declared him to be equally a fluent orator and admirable engineer. Philo also built around the port sheds or roofs for 400 triremes, which were said to have been first used at Rhodes, and originally contrived by Hippodamus. These sheds were necessary to protect their vessels from the action of the weather, and it is probable they formed the chief constructions.

This port was secured by chains stretched across it, as well as the others: it was a part of the project of Themistocles to unite the city with the Piræus by long walls. Those on the side of Phalerum were first commenced, the foundations being formed of massive stones, mixed with lime wherever the ground was at all soft or marshy. This was completed by the architect Callicrates in the time of Pericles, who also erected the wall on the other side, and the fortifications around the port.

About 410 years before Christ, when the Four Hundred Tyrants governed Athens, the promontory Eëtion was walled in, and soon afterwards the long walls built by Themistocles, with the exception of about 10 stadia on each side, were demolished by the Lacedemonians, during the reign of the Thirty Tyrants; after their expulsion by Thrasybulus, Munychia was again fortified. Conon afterwards rebuilt the walls of the Piræus, as well as the long walls; and, that they might be rendered more secure, a double ditch was cut, under the direction of Demosthenes.

In this state the port remained until Scylla set fire to the arsenal and armoury, and demolished the walls, putting it into a defenceless condition. In the time of Strabo, who lived under Augustus and Tiberius, the long walls and the fortress of Munychia were totally destroyed: there was a temple to Jupiter, which retained some curious paintings as well as statues; and as late as the second century of our era, this temple, another to Minerva, with bronze statues, a temple to Venus, a portico, and the tomb of Themistocles, remained, together with the sheds or coverings which sheltered the triremes.

The walls around the Piræus were constructed with the stone brought from the quarries close at hand, mentioned by Xenophon.

When the writer visited the Piræus in 1818, there was nothing left to indicate its former importance; its temples, porticoes, theatre, arsenals, and other magnificent structures, having all disappeared; the two lions, 10 feet high, of admirable sculpture, which were taken away by Morosini, now adorn the arsenal at Venice. At the mouth of the port two ruined piers are to be seen, which were united by a chain, stretched across for its defence; the deepest water is at the mouth of the inner port, the Aphrodisus of the old Piræus. It seems difficult to understand how, in the time of Constantine, 200 ships could have found anchorage here, or that it ever could have contained the whole of the Athenian navy, which at one period was said to consist of 300 ships of three banks of oars, the whole length of the harbour, from the outer mouth to the innermost recess, being not more than a mile and a quarter.

The ground of the peninsula called Munychia is both high and rocky, and not capable of being applied to cultivation; its shores are indented with four small natural bays. The walls which fortified it may be traced in various places nearly all round, particularly across the neck between the port of Munychia and the Piræus. The old harbour of Munychia is of a circular form, and there are the remains of several walls running into the sea, and parts of the piers on each side of the mouth, which reduced the entrance to this port, and made it much less than that of the Piræus. The walls which surrounded it are traceable on the eastern side of the harbour, and the whole extent of them appears to have been about four miles.

Between Munychia and Phalerum, and at the top of the cliff, between these two ports, is an excavation made in the rock, decorated with a pilaster on each side, rather rudely cut, which probably served for the sentinel placed there to reconnoitre. The port of Phalerum is smaller than that of Munychia, and is in its form elliptical; at its very narrow mouth are the remains of the two stone piers that formed its entrance; on the north-east side of this port the land is high and rocky, and beyond is the bay of Phalerum, two miles or more in length, terminated by the low promontory of Colias, where was obtained the clay from which the most beautiful pottery was made. From one point of this bay, which lies south-south-west from Athens, the sea may be computed at a little more than twenty stadia distant from the city; and Pausanias, who lived in the second century, gives us an account of two roads which led from thence to the ports, one to Phalerum, and the other to the Piræus: on the side of the latter, in his time, remained a part of the walls erected by Conon, and the sepulchral monuments of Menander and Euripides, that of the latter being a cenotaph or mound of earth without his ashes.

These ports were united to Athens by the long walls, traces of which on the right of the present road, which conducts from Athens to the Piræus, may still be seen. The walls of Athens, when in its prosperity, together with those which connected the Piræus, were in length 195 stadia, or 24 miles and $2\frac{1}{2}$ furlongs; those enclosing the Piræus and Munychia comprising of this quantity 60 stadia, the long walls which joined the Piræus to the city on the north side 40 stadia, and on the south side 35 stadia; and the exterior city wall, which joined the ends of the two long walls, was 43 stadia; the middle or interior wall between the long walls was 17 stadia. The circuit of the city wall alone, without the long walls, was computed at 60 stadia or 7 miles and a half, the portions towards Hymettus and Pentelicus were constructed of brick.

Thucydides informs us, that when the Athenians raised their walls after their destruction by the Persians, they used so much haste, that they united stones of various kinds and dimensions, many columns taken from tombs, and whatever came first to hand.

The breadth of the walls about the Piræus was sufficient to allow two carriages to pass upon it, and although so thick, they were entirely built of squared stone throughout, and cramped with iron run with lead.

Eleusis. The site of the ancient town, with its walls, was a short distance north-east from the port, where are the remains of three ruined moles: two of these formed the port, which was an oval; the other, which nearly divided it, seems rather to have been a landing-place; attached to this is a modern one, which springs from it nearly at right angles. The sacred way from Athens is still discernible, as is the road from Megara.

A ridge of the Icarian range of mountains separates Eleusis from the plain of Athens. Eleusis is situated in the Thriasian plain, where Ceres first gave her instructions in agriculture; the citadel stands on a low rocky hill, about 300 yards from the sea; on the declivity which faces the south-east is formed a terrace, and on this was founded her celebrated temple, which was backed by the Acropolis. Around the base, and along the margin of the Bay of Salamis, were numerous villas and residences of the inhabitants, together forming a picture of a very imposing kind. The propylea or entrance to the Acropolis equalled in beauty that at Athens. A little beyond the Sacred Way are some remains of tombs, and at about a mile distant, near the river Cephissus,

which is dry in the summer, are considerable ruins; the rise of this river is near Eleutheræ in Mount Cithæron, and in its course it passes the hill of Magoula, where the ancient stone quarries are situated; the river then divides, and both channels enter the

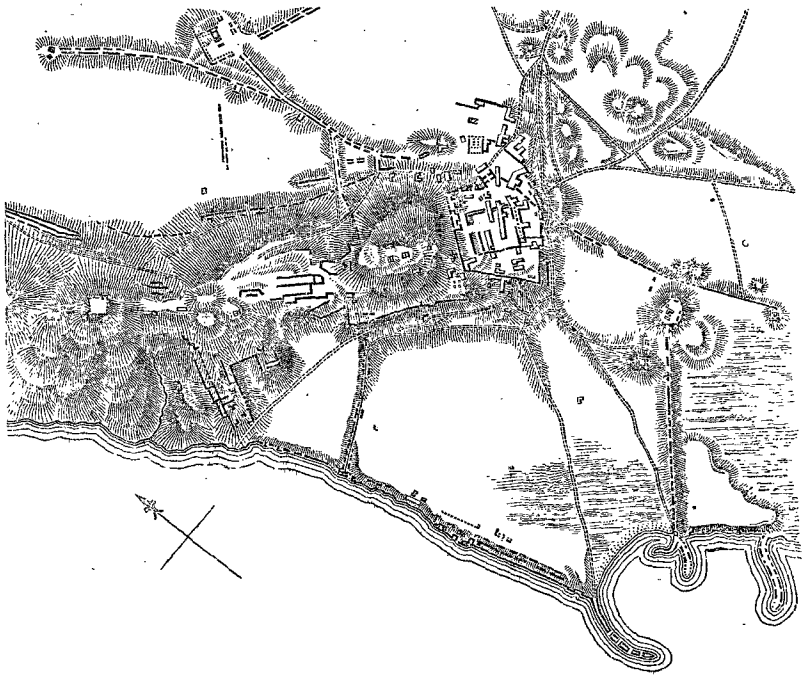


Fig. 53. ELEUSIS HARBOUR.

Bay of Salamis at about a distance of 1500 yards from each other. There are some remains of embankments to confine the water along the eastern side of the western river, and others to protect the delta formed by the Cephissus. There are some other engineering works apparent on the shore, and the ruins of an aqueduct which supplied the inhabitants of the town with water.

Corinth stands on the isthmus, on the side of the Peloponnesus, and its ports were once celebrated for their convenience and extent; hither resorted ships from Asia and Europe; it was the centre of commerce, and its citizens became the most wealthy persons of the world. Around the Peloponnesus the navigation was tedious and dangerous: it was found more easy to carry the merchandise across the isthmus from one sea to the other, and sometimes the smaller craft were transported in this way. The merchants attained to such wealth and luxury, that it was a common saying, that "every man was not rich enough to live at Corinth."

The port towards Asia was called Cenchreæ, and that towards Italy Lechæum; the latter lay beneath the city; the road to it was between long walls, 12 stadia or a mile and a half in length.

In the time of Xerxes, the Peloponnesians destroyed the Scironean way, and erected a wall entirely across the isthmus, from the port of Cenchreæ to that of Lechæum.

The isthmus which divided the two seas at Schænus, the narrowest place, is 40 stadia or 5 miles, and here was the Diolcos or drawing-place, where vessels were conveyed across on machines — a curious and early contrivance, answering the purpose of a railway.

Demetrius Poliorcetes had the two gulfs surveyed, and it being reported that the water stood higher in the Corinthian than in that at Cenchreæ, he abandoned the project of cutting a canal through the isthmus: it was feared by the engineers of the day that such a work, if carried into execution, would have flooded the island of Ægina, and done considerable mischief; in after times Julius Cæsar and Caligula turned their attention to this subject, and Nero commenced a cutting from Lechæum, and continued it for a length of 4 stadia, or

half a mile. Pausanias tells us, that all who have endeavoured to form the Peloponnesus into an island have failed; that none ever cut away the native rock, which still remains untouched; so difficult was it in those days for man to force nature.

The Corinthians were either put to the sword or sold as captives by the Roman army under the command of Lucius Mummius; and the historian Polybius, present at the siege, relates that he saw splendid pictures and exquisite works of art destroyed, and those that were conveyed to Rome became its greatest ornament. The city remained deserted until Julius Cæsar converted it into a Roman colony, when the sepulchres were ransacked, and their contents sent to the imperial city, which was said to be filled with the decorations of the tombs. Strabo, who was at Corinth after this time, describes it thus: "A lofty mountain, 3½ stadia in perpendicular height, ending in a pointed summit, was the Acrocorinthus, which was approached by a winding path 30 stadia in length. At the foot of this citadel, on a level area, was the city, the circuit of which was 40 stadia, and all that was not sheltered by the lofty mountain, was walled in; the whole circumference was about 85 stadia or 10½ miles: the view from the summit is magnificent. To the north lies Parnassus and Helicon, covered with snow; and below these, to the west, is the Crissæan Gulf, bounded by Phocis, by Bœotia, and the Megaris, and opposite to Phocis, by Corinthia and Sicyonia. Beyond are the mountains called the Oneian. Pausanias visited New Corinth after it had flourished 217 years, and he notices several temples, statues, and the agora or market-place; there was an odeum, a theatre, and gymnasium, all of which have disappeared."

The Port of Ægina was once so celebrated, that, according to Strabo, it enjoyed naval dominion, and disputed with Athens the prize of superior glory in the battle of Salamis, when the Persian fleet was defeated. The Island of Ægina is surrounded by Attica, Megara, and the Peloponnesus, each distant a little more than 12 miles or 100 stadia. Its entire circumference was 180 stadia or 22½ miles.

The port is now difficult of access, and only fit for the entry of very small vessels; a part of the ancient mole is still to be seen, constructed of large stones piled one on the other, near which, when the writer visited it some years ago, were standing two Doric columns, which formed part of the temple of Venus.

A modern lighthouse and lazaretto occupy the sites of more ancient structures, and among the ruins of the town may still be traced the museum and school or academy. In the interior of the island are remains of the splendid temple of Jupiter Panhellenius, with its numerous columns erect, standing above the north-eastern coast of the island; it was reckoned among the finest of the Greek places of worship, and considered famous for its sculpture. Vases of terracotta of great antiquity are found on the island.

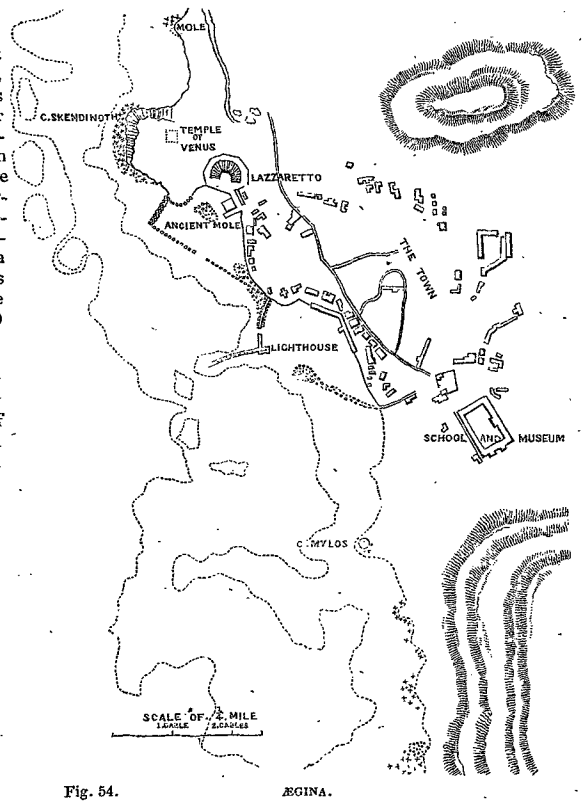


Fig. 54. ÆGINA.

Island of Rhodes, in the Mediterranean Sea, lies nearly opposite the coast of Lycia and Caria, from which it is distant about twenty miles. It is in circumference about 120 miles,

has a fertile soil, produces fine fruits and wines, and has an atmosphere of great serenity, no day ever passing without sunshine. This island was occupied by a colony of Greeks, some from Crete, and some from Thessaly, at a very early period; and Homer tells us that Tlepolemus, son of Hercules, took with him a colony from Argos to Rhodes, and afterwards joined the expedition against Troy: at that time the wealth and power of its inhabitants were considerable. He divided the island into three independent states, Lindus, Camirus, and Ialysus: the first of these, which gave birth to Chares, the architect of the celebrated Colossus, stood on the east coast of the island; Camirus, on the western coast, and Ialysus on the north side. Some time afterwards, during the Peloponnesian war, these three states were united, and the city of Rhodes, built in a very advantageous situation, became the common capital of the island, flourishing in commerce, arts, and arms, and extending its dominion over a large portion of the contiguous continent. It was situated on the east coast, at the foot of a gently rising hill, in the midst of a plain, abounding with springs and fruit trees. Strabo informs us that in ancient times few places were preferable to it.

Hippodamus, a native of Miletus, who had gained great reputation by his works at the Piræus, already alluded to, arranged the plan of the new city, and superintended the erection of the walls, gates, and public buildings. According to Strabo, its form was that of a vast amphitheatre, surrounded with walls, like those of Munychia, embellished with straight and wide streets, large squares, and numerous splendid edifices, among which was the Haleum, or temple to Apollo.

The haven or harbour was of considerable extent, and the entrance to it was by a passage between two rocks, 50 feet apart.

The Rhodians, for centuries, were famous for the study of the sciences, and by many, Rhodes was reckoned equal to Athens for the number of its learned men; the inhabitants were in amity with all nations, and their merchants, from the trade they carried on with Egypt, became so enriched, that the whole city was supported by them. It was on the occasion of Antigonus not being able to separate them from the cause of Ptolemy, that he sent his son Demetrius Poliorcetes, or city taker, with ships to intercept the trade between the ports of Rhodes and Egypt. The Rhodians, however, were successful in all the combats; at which Antigonus became so incensed, that he furnished Demetrius with additional ships, and all manner of engines to besiege their city. The fleet consisted of 200 men of war, and 170 vessels, which carried 40,000 soldiers, besides horse and auxiliaries. A thousand other vessels, belonging to merchants, followed in the train.

Demetrius drew up his fleet, which contained engines of every kind, capable of producing destruction, in the following manner:—those which discharged darts or arrows, three spans long, in front; the vessels which contained the cavalry in the second rank, and in the rear the transports, which contained corn and provisions; the whole sea being, as it were, covered with vessels. On his arrival, he landed all his men, and took his station within the cast of a dart from the walls of the city, throwing up an earth wall, fortified by large trees, as a protection against any sally from the Rhodians; he then commenced dredging the port, and rendered it sufficiently deep and spacious to hold his fleet. His next operation was to construct two engines called testudoes, which he placed upon the decks of two transports, one of which was to guard against the stones thrown by the enemy, and the other the darts and arrows discharged by the machines on the walls.

Plutarch informs us that Demetrius had a thorough knowledge of mechanics, and that in every thing he did, there appeared a grandeur of design, and so much invention, that his enemies, pleased with the beauty of his contrivances, stood looking with admiration at his galleys of fifteen or sixteen banks of oars, and his engines, which were called helepoles, in consequence of their employment in taking a city. The largest had a square base, each side of which measured 48 cubits, and its height was 66 cubits, but it diminished on all sides towards the top, and therefore resembled the frustum of a pyramid. It consisted of four stories, each having an opening for the discharge of missiles. Vitruvius informs us that these engines were made by Epimachus, an Athenian, whom Demetrius Poliorcetes had in his train, and that it was secured by hair cloths and raw hides, so that it might withstand the shock of a stone 360 pounds weight, thrown from a ballista. The entire machine, it is said, weighed 360,000 pounds.

At this time, Diognetus the architect was paid an annual salary for his skill in maintaining the walls and places of defence; but during the siege, Callias, an architect of Aradus, arrived and exhibited a model of a wall with a revolving crane, by means of which he could suspend an helepolis near the spot, and swing it within the walls. When the Rhodians saw this, they dismissed Diognetus, and appointed Callias to fill his situation, and to prepare his machine against the helepolis, and swing it within the wall, as he had promised; when he was obliged to confess his inability. Diognetus was then entreated to aid his countrymen, and he consented, upon the condition of having the machine if he succeeded in removing it: this being agreed to, he ordered a hole to be made in that part of

the wall opposite the machine, and water, filth, and mud to be thrown on the other side and discharged through the hole during the night: when the helepolis advanced, it sunk in the quagmire, and Demetrius drew off his army.

Diognetus then removed the machine within the walls, and placed it in a public situation, thus inscribed: — "Diognetus presented this to the people out of the spoils of war."

Demetrius also had upon the sea a floating tower, with loopholes at the sides, from whence darts could be discharged; this was formed upon a number of boats, which were attached and floored over with a common platform. The Rhodians had in this memorable siege contrivances of the same kind, and placed them at the mouth of the small harbour; in which were engines for the throwing of stones, darts, and arrows of all sizes. Demetrius was at first prevented entering by a storm, but was afterwards enabled to seize upon the highest rampart of the great harbour, and throw up a mud wall around it, fenced and secured with piles and planks as well as stones; here he landed 400 of his men, who were within five plethras of the walls. Demetrius continued his assault for many days, sometimes burning and destroying the vessels in the harbour, at other times making breaches in the walls; but the bravery of the Rhodians at last obliged him to desist. The Rhodians had scarcely repaired the walls which were beaten down by the engines brought against them, when Demetrius again returned with other battering engines, and with his ships entered the harbour, throwing firebrands among the Rhodian ships, which were soon extinguished. The Rhodians then manned three of their strongest vessels with their ablest men, and ordered them to act against the enemy's vessels which contained the engines; these they violently charged, and though they were fenced with iron, they broke them in pieces with the prows of their ships, and shattered them, taking Execestus, who commanded the galleys, prisoner. Demetrius made another engine thrice as large as the former, which was destroyed in a storm as it advanced into the port; he then abandoned his attacks by sea, confining his assault of the city to the land, and framed another helepolis much larger than either of the former; its base was square, the length on each side being 50 cubits, formed of four square pieces of timber, united together by plates of iron at the angles. Strong transverse timbers were laid from one side to the other, a cubit apart, on which was the floor for those to stand upon who moved the engine. The whole rested on eight strong wheels, the fellies 2 cubits in thickness, also covered with iron; over the spokes were antistreptas, which enabled them to turn the engine round when required. At each angle was a perpendicular piece of timber 100 cubits in height, with floors thrown in at regular distances, which tied them together, and made the machine nine stories. In the lowest were forty-three beds, and in the highest nine; three of the outer sides were cased with iron plates, to prevent fire or any other injury to which it might be subjected from the besieged. In the front, each story had a number of loopholes, guarded with shutters lined with skins stuffed with wool, which deadened the force of any stone shot against it, and two ladders: to move this vast machine 3,400 men were appointed, some being placed within, and others around it.

Testudoes, or artificial covers, made of timber covered with raw skins, protected the men employed in levelling the ground to the city wall, over which this engine was to be moved; and when the helepolis was against the city wall, its breadth occupied the space of six divisions between the turrets, and the seven turrets: the workmen and artificers of different kinds employed are said to have been 30,000.

The Rhodians built within the outer wall of their city another, and employed for its construction the stones of the theatre, several houses and temples, and in a general assembly proposed to destroy the statues of Antigonus and Demetrius. The city was, however, by this time undermined, when the Rhodians cut a deep trench along the wall that it was intended should be thrown down, commenced countermining, and soon met the enemy under ground, and prevented any further progress being made.

The helepolis, with eight testudoes made for filling up the trenches, and others containing battering-rams, which were 120 cubits in length, strongly armed with iron, and resembling the beak of a ship, were moved forward on wheels by the help of a thousand men. The several stories of the helepolis were filled with archers, and at a given signal the walls trembled under the strokes of the battering-ram, one of the strongest towers was thrown down, and the entire wall between it and the next so shaken, that the besieged could not pass along it.

Ptolemy having sent a fleet with succour, inspired the Rhodians with fresh energy; they made an attack on the enemy's engines, and by means of fire-balls and weapons of all kinds, at last succeeded in destroying the iron plates which protected the helepolis, and then with firebrands set light to it. Demetrius endeavoured to quench the spreading flames, to move the engines from the reach of the darts discharged against them, and to make a general reparation of them. The Rhodians, in the mean time, commenced a third wall, built in the shape of a half moon, which enclosed the gap already made. Deme-

trius renewed the attack with all his vigour, and at night determined to carry the city by assault: a great slaughter on both sides was the result; but the Rhodians were triumphant, and forced Demetrius to accede to the following terms: — "That the city should be subject to its own laws, and be left without a garrison." Thus the Rhodians, after a twelvemonth's siege, put an end to the wars, soon afterwards repaired the theatre, and rebuilt the temple and walls.

By some historians it is asserted that Demetrius was at last so reconciled to the Rhodians, and so much admired the courage they had displayed, that he presented them with all the engines he had employed, and that it was by the sale of these for 300 talents, that they raised the famous Colossus on the two rocks at the entrance of the port, which was a statue of brass, erected in honour of Apollo, the tutelary god of the island; it was 70 cubits or 125 feet in height, and vessels could pass between its legs.

Pliny describes it as the work of Chares of Lindus, a pupil of Lysippus, and observes that its thumb was a fathom in circumference; that it was made hollow, and had a lining of stone, to render it steady on its feet. It stood erect for sixty years, and was thrown down by an earthquake, which Polybius tells us destroyed the walls and naval arsenals at the same time. The Colossus, however, lay where it fell for 894 years, until Moavias, the sixth caliph of the Saracens, sold the metal to a Jew, who loaded 900 camels with it, the weight being estimated at upwards of 300 tons.

The Rhodians, after its fall, and the injury their city had sustained, solicited help from the kings of Egypt, Macedon, Syracuse, Syria, Pontus, and Bithynia, to enable them to restore it. From Hiero and Gelo they received 75 talents of silver, some silver caldrons, and other presents, which together were valued at 100 talents, and also 50 catapults of the length of 3 cubits.

Ptolemy engaged to furnish them with 300 talents of silver, a million measures of corn, timber to build 10 quinqueremes, and 10 triremes, some square pieces of fir, the contents of which were 40,000 cubits, 1,000 talents of brass coin; 3,000 weight of hemp, 3,000 pieces of cloth for sails, 3,000 talents for replacing their Colossus; 100 architects, and 350 labourers; with 14 talents by the year for their subsistence; 12,000 measures of corn for the sacrifices and games, and 20,000 for the 10 triremes.

Antigonus gave them 10,000 pieces of timber that would cut into scantling from 8 to 16 cubits; 5,000 planks of 7 cubits; 3,000 weight of iron; 1,000 measures of pitch, and 1,000 measures of tar, as well as 100 talents in money.

Chryseis, his wife, sent 100,000 measures of corn, and 3,000 weight of lead.

Seleucus, the father of Antiochus, gave 10 quinqueremes completely equipped, 200,000 measures of corn, 10,000 cubits of timber, and 1,000 weight of hair and resin.

By all these and other gifts, Polybius tells us, the Rhodians soon restored their city to its former magnificence; but they were ordered by the oracle at Delphos not to replace the Colossus, but to use the presents they received for other purposes.

Isene is another ancient port, which once contained a fine harbour: its ruins proclaim

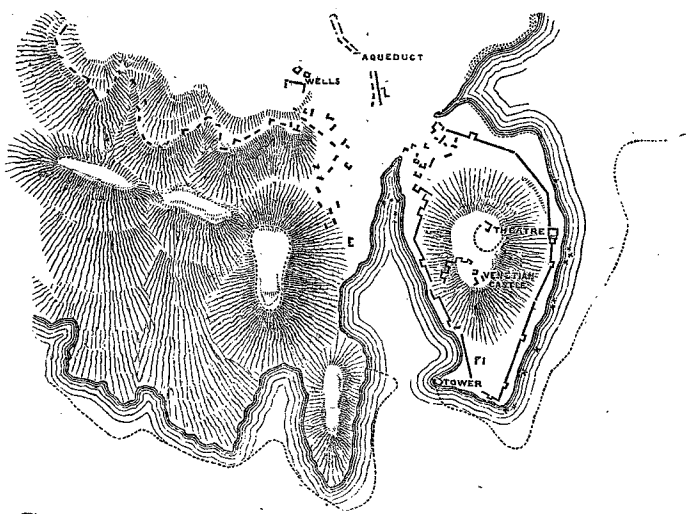


Fig. 55. ISENE.

its importance. Walls of the theatre, aqueduct, and public buildings may yet be traced, around the site of the castle erected in the middle ages by the Venetians.

Samos was a name common to three islands, Cephalonia, Samothracia, and Samos, which lay between the continent of Asia and the island of Icaria, being divided from the former by a strait, which, according to Strabo, was equal to 1000 paces in breadth, and from the latter by another 8 miles across. At the present day all the vessels going from Constantinople to Egypt and Syria pass through either one or the other of these straits. The island of Samos measures about 87 miles in circumference, and from Vitruvius we learn that Samos, and the thirteen Ionian towns, were built by Ion the Athenian. Samos was very populous, wealthy, and strongly fortified; and most deserving the notice of an engineer, from the three remarkable monuments of art mentioned by Herodotus; one of which was a passage cut through a mountain, 150 orgyia high; the length of which is 7 stadia, and 8 feet in width and height: by the side is a canal 3 feet in breadth, and 20 cubits deep, also made by art, which supplied water from a copious spring. Eupalinus, the son of Naustrophus, an inhabitant of Megara, executed this work. Tournefort observes that in the valley, near to the aqueduct, are several caverns artificially cut: the spring which fed this canal was doubtless that of Metelinous, the best in the island: but it does not appear that the levels were accurately taken, otherwise the depth need not have been so great; and indeed it does not seem very practicable to dig a trench 20 cubits deep and only 3 wide.

The second was a mole, which projected from the harbour into the sea, 2 stadia in length, and 20 orgyia, or upwards of 120 feet, in height.

The third was a temple erected by Rhœcus, son of Phileus, who was the inventor of the art of making moulds with clay. Long before the Bacchiades were driven from Corinth, Rhœcus and Theodorus of Samos made casts in brass, and formed statues.

The tunnel through the mountain has been long filled up, but the entrance may still be discovered; there are no vestiges of the stupendous mole, which must have been a wonder among the Greeks at such an early period. That the Samians were devoted to maritime affairs, we learn from their having, 300 years before the Peloponnesian war, employed Aminocles the Corinthian, the most skilful ship-builder of his time. They traded to Egypt, Thera, and Spain, and, according to Pliny, they were the first who built vessels for the transport of cavalry. Samos was famed for its earthenware, and had a considerable manufacture of it. In all parts of Europe, we find examples of Samian ware; in the tumuli and monuments of the Romans, vessels of this manufacture are discovered; sometimes admirable for the beautiful forms they present, the ornaments with which they are covered, and always for the perfection of the workmanship. Vases, lacryma, lamps, and cups, made at Samos, the writer has discovered at Athens, Sicily, and in Italy. In the broken pottery, which the tumuli in France and Italy often afford, fragments of Samian ware, covered with intricate chasing and highly ornamented, are often found.

Tenedos is a rocky but fertile island; its position, near the mouth of the Hellespont, has caused it at all times to be a place of considerable importance. Its circumference is about 10 miles, equal to 80 stadia. The port was enclosed by a mole, but at present there is no portion to be seen above water; the ancient foundations remain, on which are piled loose stones, for the purpose of breaking the force of the waves; a ridge of mountains surrounds the harbour, which gives shelter to vessels bound to Constantinople. Here the Emperor Justinian erected a magazine, 280 feet in length, 90 feet in breadth, and many stories in height, for the purpose of warehousing the corn brought from Egypt, as it often occurred that stormy weather during the Etesian winds prevented the ships from pursuing their voyage.

On this island still remains an ancient stone building, in which the water used by the inhabitants was collected, after it was brought from distant springs, in earthen pipes.

Troas. The port has a hill rising around it, in a semicircular form, covered with ruins; and near the shore are many small columns of granite, injured by the spray of the sea, and partly buried in the soil, to which were made fast the vessels trading to this port. At present the smaller basin is dry, and a bar of sand closes up its entrance, but the larger has shallow water in it. These two basins were both the work of art, and intended only to receive galleys and small vessels; larger ships being obliged to cast anchor in the road, outside the mole.

Alexandria Troas is the name given to the town, it being one of the eighteen called after Alexander the Great, who caused cities and temples to be erected, and improvements to be made, throughout the countries he subdued: it was first called Antigonia; but its name was afterwards changed by Lysimachus in honour of the deceased sovereign. Augustus showed it considerable favour, under whom it increased in wealth, and was benefited by a Roman colony. The city, which is several miles in circumference, has its wall, of considerable thickness, still standing; at regular distances it is strengthened by square towers. The aqueduct which supplied it with water may be traced for several miles; the piers are 5 feet 9 inches in width, 3 feet 2 inches in thickness, and the arches, though destroyed, were upwards of 12 feet in height. This was one of the structures erected at the private cost

of the Athenian Tiberius Claudius Atticus Herodes, who was appointed to preside over the free cities of Asia. When this munificent and illustrious proconsul found that Troas was not supplied with water, he requested of the Emperor Hadrian, that he would not allow this ancient maritime city to be without a plentiful supply, but that he would bestow 300 myriads of drachms to procure it. Hadrian complied, and appointed Atticus Herodes to superintend the constructions necessary. Upwards of 700 myriads were expended, and the emperor complained; when Herodes in reply stated, he had given the overplus of the sum to his son, and he to the city. This munificent Athenian was the grandson of Hipparchus, who, though wealthy, had his estates confiscated, and his family reduced to the greatest want: but his father, Julius Atticus, discovered a vast treasure in a house which he inhabited, near the theatre at Athens; of which he informed the Emperor Nerva, and requested to know his pleasure in the appropriation of it. The emperor replied, "Use what you have found, and abuse, if you will, what Mercury has given you." After this Julius married a wealthy lady, and their son, Atticus Herodes, who was born at Marathon, inherited a vast property: his education was superintended by the most learned masters; and he became as eminent for his mental acquirements, as for his wealth: in the year 143 he was made consul with Torquatus at Rome.

Chios. This island was computed by Strabo to be 900 stadia in circumference, or about 112½ miles, and about fifty miles from the island of Mitylene. The ancient city of Chios had a good port, large enough to admit eighty ships. The present town of Scio occupies the

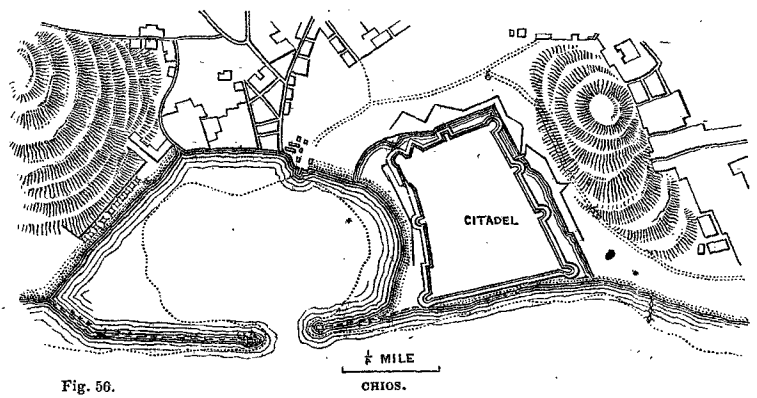


Fig. 56. CHIOS.

site, and there may still be traced the remains of the ancient mole, which above the level of the water is now covered with large loose stones. The entrance to the port beyond this mole is narrow, and encompassed by rocks. A modern citadel takes the place of a part of the more ancient town, the ruins of which still remain.

Smyrna was founded by Alexander the Great, for the Smyrneans, a people then living in the neighbourhood of Ephesus; and the situation chosen indicates the judgment which the Greeks always bestowed upon such occasions. This city, like others of their founding, is on rising ground, near a plentiful supply of marble, and where in the side hills might be cut the stadium and the theatre.

The port originally reached to the foot of the Acropolis, at which time it was a spacious basin in the midst of the city, encompassed with strongly-built and lofty walls, the stones being laid in regular courses; a great part of which may be still seen. Tamerlane ruined the ancient port by not allowing the sea its free ingress, and thus permitting the waters of the rivers to deposit their mud, without means being adopted to remove it. This emperor, who ravaged Asia, at the commencement of the fifteenth century, commanded every soldier in his army to throw a stone into the mouth of the harbour, which soon choked it up. The ancient city was two miles and a half from the modern Smyrna, and was built on the sea-shore, with the fine and clear river Menes running at the foot of the walls.

The Gulph of Smyrna, about 10 leagues in length, is well sheltered, and affords excellent anchorage. The mouth of the Hermus is on the north side, within two leagues and a half of the modern city. The mountain which bounds the bay of old Smyrna on the north extends westward to a plain through which the river runs. Near the mouth of the river is a shoal or sandbank, and the channel is very narrow. The Hermus appears to have frequently changed its course, and in time the plains around the modern city will probably be covered with water, thus placing it in the midst of a vast lake.

Teos. This ancient port is now partly dry, and many sandbanks have been thrown up

above the level of the water; the town itself has long been deserted, though there are traces of its walls, which appear when perfect to have been 5 miles in circuit. Pliny describes Teos as an island, and the rocks around it furnished excellent building materials. It was thirty stadia from Geræ, and fronted the sea on the south.

Ephesus is situated on a plain, watered by the Cayster, and the wall erected by Lysimachus, which is of excellent masonry, may still be traced in many situations, particularly at the back of the stadium near Mount Prion, where it remains 20 feet in height; from thence again over Mount Corissus, where it is nearly entire.

Mount Prion contained the quarries of marble made use of for building the celebrated temple of Diana.

The port, which received the flux and reflux of the sea, has now its once wide entrance choked up with the deposits of the river Cayster; and Attalus Philadelphus and his engineers were of opinion that by contracting the entrance the harbour would have recovered its depth, and have been rendered capable of receiving vessels of considerable size. The ancient port is now a morass, and the wall, erected to embank the stream, and by confining it to give it additional force, is of excellent masonry, formed of large stones in regular courses throughout, and at the ferry a considerable portion may yet be seen.

Crete. This island, now called Candia, is one of the largest of the Mediterranean, being 287 miles in length, and 65 miles in the widest part. It lies between the thirty-fourth and thirty-fifth degrees of north latitude, and was by the ancients celebrated for its fertility. At one time it boasted of its hundred cities, ninety of which were established before the Trojan war; and after the Dorians had founded the other ten, it was called Hecatompolis.

Gnossus, anciently Ceratus, was the capital, and here Minos held his court: it was 30 furlongs in circumference, but modern travellers have not yet decided where it was situated.

Gortyna eclipsed all the other cities of Crete in splendour and magnificence; the ruins are still traceable, six miles from Mount Ida, at the commencement of the plain of Messaria. Tournefort describes one of the gates, with a beautiful arch, and part of the wall which Ptolemy Philopater, according to Strabo, erected. There were also some columns of granite fluted in a spiral manner, of exquisite workmanship. The walls were washed by the river Lethe.

Rethymna, now Retimo, had at one time a convenient haven, and Heraclea, which was opposite the island of Vea, was the seaport of the Gnossians, and occupied the site of the present Candia.

In the island are many creeks and bays, with several safe and capacious harbours.

Phalasarna, on the western extremity of the island of Crete, has on its northern side many remains of its city walls, which appear to have extended to the sea, and cutting off the Acropolis and city, so as to form a small promontory.

The walls near the sea on the north side exhibit the remains of many square towers, the distance between being about 120 feet, and some 230 feet. One of these towers measures on the face 36 feet, and projects 20 feet from the wall.

The walls are not continued in regular lines, and in some parts are the remains of another, placed at a distance of 16 feet from the first; and it seems probable that originally the whole city had a double wall from one sea to the other, where the distance is about 500 yards.

Cyprus or *Ærosa.* This island extends from east to west along the coast of Cilicia for about 180 miles, and is in breadth about 45 miles. It lies between the thirty-fourth and thirty-fifth degrees of north latitude, and is one of the most productive islands of the Mediterranean. It was first peopled by a colony from Phœnicia, about 1045 years before Christ, and the principal cities were on the north side of the island.

Neapaphos, according to Strabo, was founded by Agapenor, the nephew of Lycurgus. It was famous for its harbour, which was totally destroyed by an earthquake. There was an abundance of copper, formerly found in metallic masses, employed by the ancients for fabricating their agricultural implements and weapons of war; the inhabitants of this island having been well instructed in the arts by the Phœnicians.

The ancient harbour of Arsinoë, where the modern town of Famagusta stands, is now choked up with sand. In the Gulf of Larnica stood the town of Citium, still a place of some trade; but Salines, which takes its name from the Salt Lakes, is the chief port.

Paros, so famous for the whiteness of its marble, is 36 miles in circumference, and has several safe and capacious harbours, and formerly carried on considerable commerce. The city of Paros was one of the largest in this archipelago, and the modern Parichia is formed out of its ruins; the walls which surround it are composed of fragments of temples and public and private buildings.

This island was first peopled by the Phœnicians.

Delos contained at one time a city which was considered the richest after the destruction of Corinth; it became the emporium of commerce, and was as renowned for its trade as for its celebrated oracle. Among the ruins of Delos, which extend from one coast

to the other, are the remains of a curious arch and many stately buildings. The trunk of the famous statue of Apollo, which is described by modern travellers, is of a gigantic size, though cut from a single block of marble; the circumference of the thighs are 9 feet; and

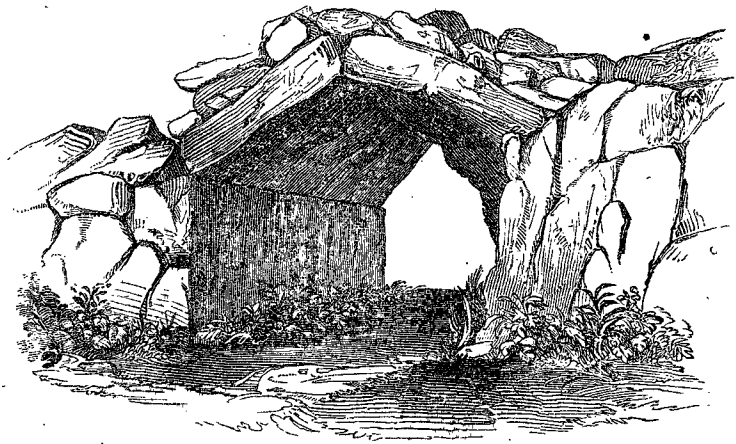


Fig. 57. DELOS.

an inscription tells us that it was dedicated by "the Naxians to Apollo." According to Plutarch, there was set up by Nicias a large palm tree made of brass, which a violent wind threw down, and, at the same time, destroyed this celebrated statue.

This island was only 7 or 8 miles in circumference, though there is another island of the same name, of double this size.

The smaller Delos was the sacred island of Apollo, and in the time of Polycrates it was united to the island of Rhea by a chain. There was held here an ancient festival, described in one of the Homeric hymns, as celebrated by the long-robed Ionians; and on one of these occasions Nicias, who was the Theorist appointed to conduct the sacred chorus, displayed his wealth and munificence by constructing a bridge, 600 yards or more in length, across the channel which separated Delos from Rhea; this bridge, hung with tapestry and paintings, served for the procession to pass. An ancient inscription, brought to England by the Earl of Sandwich, the date of which is 374 years before Christ, mentions these ceremonies, and gives some account of the offerings on the occasion.

Plutarch says in the life of Nicias, that he took care to have this bridge constructed before he left Athens, and that it was magnificently gilded, adorned with garlands and rich hangings; and then, in the night after his arrival, and before the break of day, he had it thrown across the strait, ready for the procession and the chorists, who were richly habited, to pass over. This, in all probability, was a timber construction, resting on boats, or some other buoyant arrangements.

Cnidus has two harbours, separated by a narrow isthmus, the smaller opening to the north, the other to the south, near the extremity of which are the remains of the city walls; inserted in them are many stones of considerable dimensions, which probably formed a part of the foundation of a tower on the edge of the sea. The broken cliffs extending along the shores show the ruins of the Acropolis, surrounded with strongly-built walls, and strengthened with towers at regular distances.

Here are the remains of a theatre with its marble seats, the arches and walls of the proscenium, and the ruins of one or two magnificent Corinthian temples; also a forum or agora, with a long colonnade of the Doric order, probably a stoa. An arched gateway of plain and solid masonry terminates the street which ran from the port towards the Acropolis. Above are many platforms cut out of the rock, which have served for sites of either temples or public edifices; and amongst the ruins are several marble slabs, channelled out for water conduits.

The narrow isthmus, which separates the two harbours, in Strabo's time was an artificial mole, built over a channel of the sea; and the western part of the town stood on an island united by this isthmus to the continent. An arch still remains by the side of it, and probably formed a part of the mole; but the ruins have so accumulated, and the sand so spread over them, that a neck of land is now formed 60 or 70 yards across.

Strabo tells us that the port on the north was shut in by gates, and two towers may be traced at the entrance, to which these gates were attached: it contained, he says, twenty triremes.

The southern port is much larger, and protected from the sea by a mole of large, rough-hewn stone, which still remains.

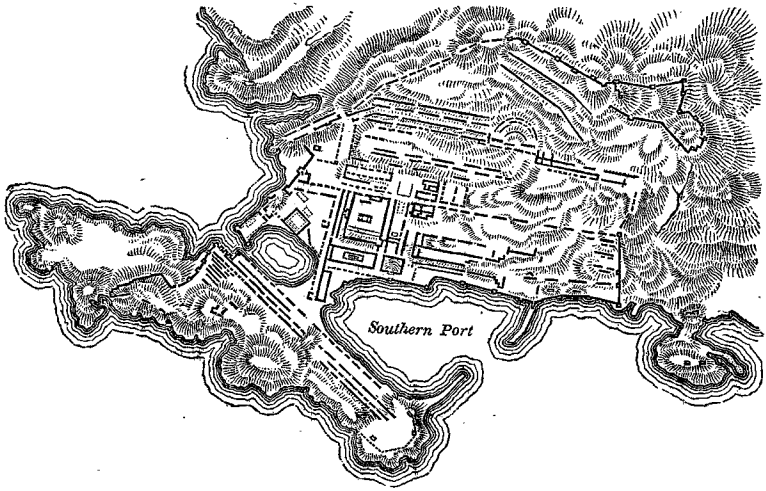


Fig. 58. CNIDUS.

Beyond the ports, to the west, the city rose on a hill, the form of which Strabo compares to a theatre, bounded from the mole, on the south, by rocky precipices, and on the north by the walls, which descended from the ridge to the gates of the northern harbour, in a semicircular sweep. On this side of the city are still many foundations of ancient houses to be traced, but no buildings of marble. The entire circuit of the walls is about 3 miles, including the two ports within them.

Halicarnassus, now the port of Boudroun or Bûdrûn. Its entrance is from the south-

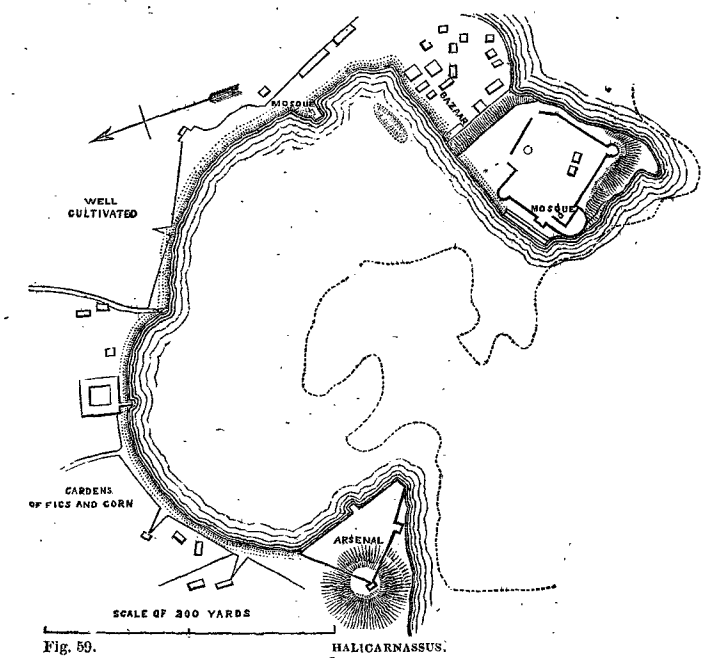


Fig. 59. HALICARNASSUS.

west; on the right and left of which a great quantity of sand has accumulated, and the passage, now free, is not more than 60 yards in width: there are some yards for the building of vessels. The small town now inhabited stands on the east side of this large and deep port. Off the bay lies the island mentioned by Strabo as Arconnesus (lib. xiv.).

Behind the town are the remains of an edifice of the Doric order, composed of grey marble, but not of the same proportions as those of the purer days of Greece, which is supposed to have belonged to the agora mentioned by Vitruvius.

Where the modern Turkish fortress called the Castle of Bûdrûn is, at the eastern end of the greater port, stood the palace of Mausolus, the smaller port being formed by the island of Arconnesus.

According to Vitruvius, Mausolus was a powerful king, and constructed here a magnificent residence, which was standing in the time of Pausanias (lib. viii. cap. 16.). Vitruvius informs us that it was built of brick, covered with slabs of Proconnesian marble, so highly polished that they sparkled like glass: he also tells us that this king was born at Mylasa, and established himself here on account of the situation being so well fortified by nature, and the port admirably adapted for commerce. The site of the city resembled an amphitheatre: in the lowest part, near the harbour, was built the forum: up the hill, in the middle of the curve, was a large square, in the centre of which stood the Mausoleum, reckoned among the seven wonders of the world. On the summit of the hill was the temple of Mars, with its colossal statue sculptured by Leocharis: on the right was the temple of Venus and Mercury, near the fountain of Salmacis. This place was colonised by Melas and Arevanias, who were driven out of Argos and Trœzene by the Carians and Lelegæ.

The palace of Mausolus commanded on the right, a view of the forum and the harbour, as well as the whole circuit of the walls, and on the left, it overlooked a private harbour, which was so contrived amid the mountains that no enemy could pry into it. From this palace Mausolus could direct both his soldiers and sailors.

Upon the death of Mausolus, the Rhodians, indignant at his wife, who succeeded to the government of Caria, fitted out a fleet for the purpose of seizing her kingdom. When the queen, Artemesia, heard of it, she commanded her fleet to remain quiet in the secret harbour, and her soldiers to man the walls. On the Rhodian fleet entering the large harbour, she ordered the citizens and those who were on the ramparts to hail them, and to promise to surrender up the town. The Rhodians eagerly left their ships, when Queen Artemesia suddenly opened a canal, brought her fleet round, and entered the large harbour, whence the Rhodian fleet, thus abandoned, was easily carried out to sea. The Rhodians, having all retreat cut off, were surrounded and slain in the forum. Artemesia, then embarking her own sailors and marines on board the Rhodian ships, set sail for Rhodes; where the inhabitants, seeing their vessels decorated with laurels, imagined their fellow-citizens had returned victorious, but received their enemies. When Artemesia had taken Rhodes, she slew the chief of the citizens, and raised two brazen statues to commemorate her victory: one of these represented Rhodes, the other herself, imposing a mark of infamy on the city, which, as it was always contrary to the religion of the Rhodians to remove a trophy, they encircled with a building.

The remains of walls and square towers are visible for a great extent, continuing for a distance of six miles from the western horn of the port, along high grounds to a considerable eminence, and then to the eastern promontory, on which the modern castle is built. On the highest point of this eminence are traces of the ancient walls, indicating the arx media, mentioned by Vitruvius, where the temple of Mars stood. At the foot of the hill are the remains of a theatre fronting the south, cut out of the side of the hill, where the steps show the position of the marble seats.

The modern castle stands on a tongue of land at the eastern extremity of the port, which it commanded: it is constructed of materials brought from some more ancient buildings. This may be the site of one of those fortresses described by Strabo, lib. xiv., as remaining when Alexander took the city.

The Fort of San Pietro was taken by Philibert de Nailar, the Grand Master of Rhodes, and was in the possession of the knights until it was surrendered to the Ottomans in the year 1522.

The Island of Cos, now called *Stanchio*, was an ancient port, at present defended by a fortress of considerable strength, with a moat on the land side. Columns of cippolino, breccia, granite, and marble are found in the modern buildings, which attest the importance as well as splendour of the former city. The mosque is entirely of marble, brought from the ruins of temples; and the antiquary, by searching within the walls for inscriptions and ornaments, may understand the character of the original structures which have been demolished.

The ancient port is filled up with soft mud, and there are no remains of any mole; though probably, by a diligent search among the foundations of the fortress, some might be

discovered. The modern landing-place has extended farther into the sea, which is here entirely landlocked towards the north. In the wall of the quay, facing the port, are worked up fragments of ancient statues.

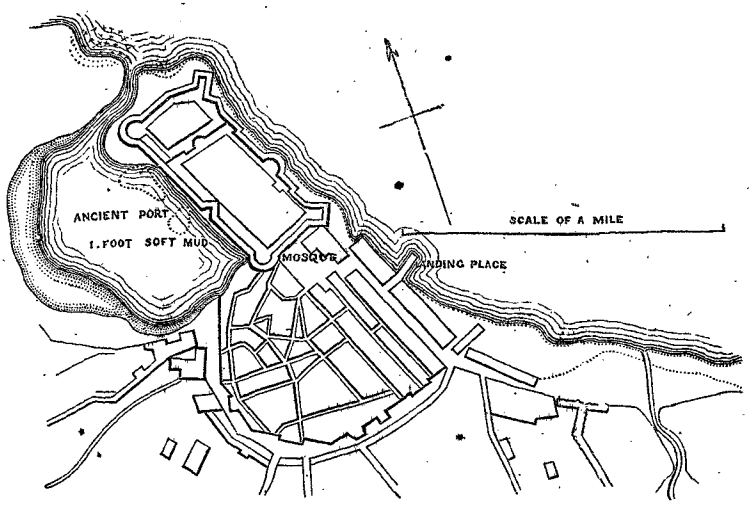


Fig. 60. COS.

The island of Cos gave birth to Apelles and Hippocrates, the members of whose schools were consulted by the inhabitants of all the neighbouring islands; the remains of an aqueduct which conveys water for a distance of three miles into the town, still bear the name of the latter; the top has been destroyed, to allow the women of the island more readily to obtain it, which is excellent, as it flows from a mountain of limestone, of which this island, as well as the others in these seas, is composed.

Myndus. Here are the remains of a long stone jetty, built with two parallel walls, 13 feet in width, connecting the island with the mainland; this ancient port is not far distant from Halicarnassus, and a modern jetty now nearly shuts in the mouth of the harbour. The part which constituted the island is covered with walls, amid which are the traces of ancient foundations. The Libs, or south-west wind, often commits great ravages on this coast, and renders navigation difficult.

Herodotus informs us that the first maritime power in these seas was obtained by Minos the Cnossian, who, according to Diodorus Siculus, established many cities in Crete, and founded some equitable laws for the government of the inhabitants. With his fleet he conquered all the islands in these seas, and was the first of the Greeks who acquired dominion; after which he arrived at a high pitch of glory by reason of his justice and valour, and died in Sicily whilst carrying on a war against Cocalus. Thucydides observes, that this naval hero commanded the islands called Cyclades, expelled all the Carians from them, and sent colonies under his own sons to supply their place. The Carians settled on the continent of Asia, where Myndus was one of their chief ports. Pliny names several free cities near it, as Palæmyndus, Nariandus, Neapolis, Caryanda, Termera, and Iasus, in the gulf so called. Rhadamanthus, brother of Minos, also reported to have been the progeny of Jupiter and Europa, shared in the government of the islands above mentioned, and Chios became the seat of government soon afterwards under a son of Minos and Ariadne. The heros or captains of this fleet had bestowed upon them either an island, or a port upon the continent; and Diodorus Siculus gives Lemnos to Thoas, Cyrnus to Engyeus, Peparethos to Pamphilus, Maronea to Euambeus, Paros to Alcæus, Delos to Arrion, and Andros to a hero of the same name. Neither the ships, nor ports which received them, are described by any ancient authors in a manner to give us an idea of their form or adaptation.

Some of the paintings taken from the walls of the houses at Herculaneum and Pompeii, show us the forms of the vessels, character of their landing places, and stupendous moles; but it has not been possible to identify these representations with what remains at any of the ancient ports. Medals also exhibit the ships in use, but not in a manner to convey a very clear idea of their figure.

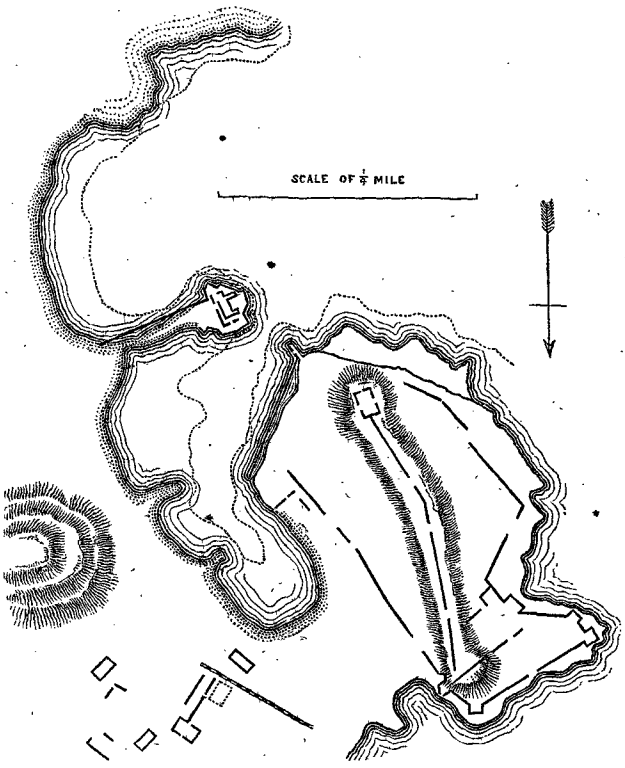


Fig. 61. MYNDUS.

Palermo. This harbour is very much exposed to the swell of the sea from the north-east; and the anchorage for ships is dangerous when the wind blows from the west. In former

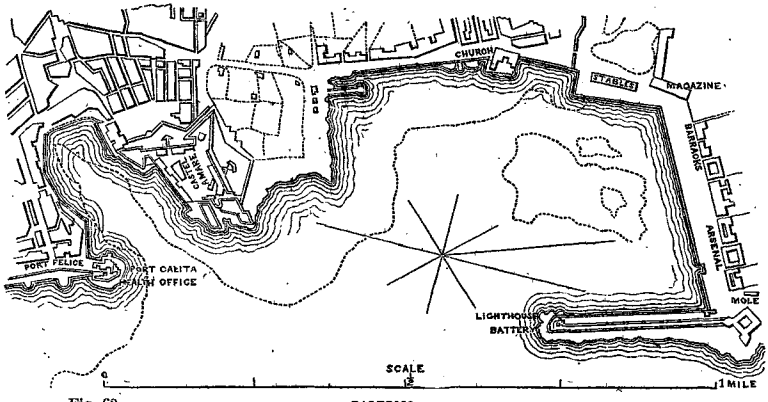


Fig. 62. PALERMO.

times the harbour was composed of two long creeks, about 150 feet in breadth, which extended into the city, and was enclosed towards the sea by a boom; but about 1550 it became so silted up that it was built over. The Phœnicians, the Greeks, the Romans, and Normans have all contributed to form this beautiful harbour, which is now shut in by Port

Cailita, or Health-office, on one side, and the mole terminated with its lighthouse on the other: here stands Palermo amidst its plains covered with convents, villas, and palaces, forming one of the most splendid prospects in the world.

The Marina, a raised public walk, more than a mile in length, and 240 feet in breadth, is defended by a parapet wall.

Syracuse. This ancient maritime city, built upon a rock, may, at the present day, be traced in many places, as may the excavations in the natural stone, where the walls of both public and private buildings were raised. The direction of the principal and transverse streets may be followed by the channels cut to the depth of six inches in the rock by the carriage wheels.

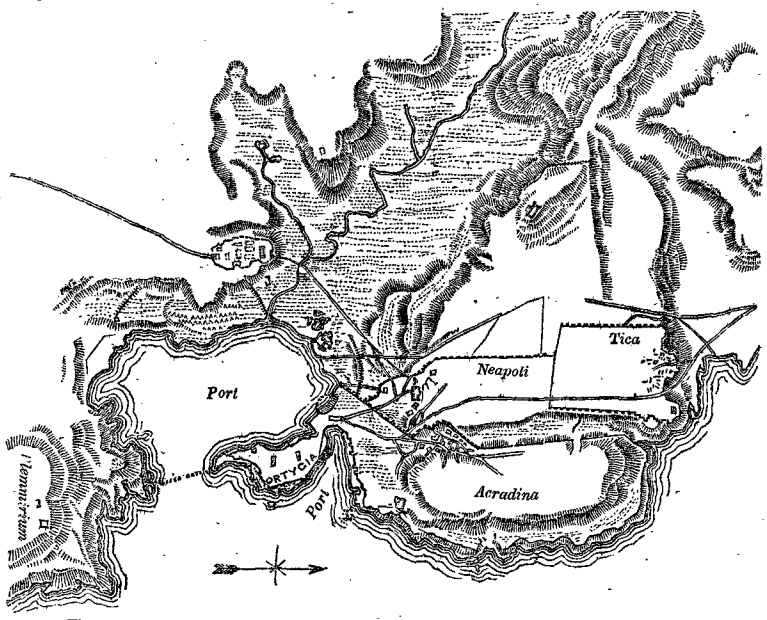


Fig. 63. SYRACUSE.

The boundary walls, constructed of stones of large dimensions, worked perfectly square, and laid without either cramps, cement, or mortar, in many situations remain perfect, to the height of 6 or 7 feet.

Syracuse was one of the most populous as well as powerful cities of antiquity. When it was besieged by Marcellus, about 213 years before Christ, it contained 1,800,000 inhabitants. It was divided into four quarters, separated from each other by lofty walls. Cicero, in one of his orations, observes, that Syracuse was the largest and most magnificent city in Greece, that its two ports were almost enclosed by nature, and that at their junction an island was formed, which was united to the city by means of a bridge thrown across the strait. The first part of the city called Ortygia, was on the island above mentioned. This, advancing into the sea, covers the entrance to both ports; and on it was situated the palace of Hiero.

The second part of Syracuse was called Acridina, containing a spacious square, porticoes, a prytaneum, or building in which the council assembled, a temple dedicated to Jupiter, and a wide street running from one end to the other, with others at right angles, in which were the private houses.

The third division was Tyca, which had a temple to Fortune, a gymnasium, and several public buildings. This quarter was the most populous.

The fourth division was the last built, and called Neapolis: here are the remains of a large theatre, two temples, one dedicated to Ceres, the other to Proserpine.

The boundary of the ancient walls, according to Strabo, was 180 stadia, or 22½ miles, including the Epipolæ, one of the suburbs, which commanded the whole city.

The Great Port is about 5 miles in circumference, and to render it more secure against an enemy, a strong chain was stretched across it from the island to the opposite rock, Plemmyrium, a distance of about half a mile.

On the other side of Ortygia is the lesser port, called formerly the Portus Marmoreus, in consequence of its being paved with marble. One of the most memorable events in history is the taking of Syracuse by Marcellus, a little more than two hundred years before Christ: in its defence was employed Archimedes, the greatest engineer among the ancients, who was singularly skilled, according to Livy, in the science of astronomy and geometry; and also eminent for his invention and construction of warlike engines, by means of which, with very slight exertions, he could baffle an enemy.

When Marcellus marched against Syracuse, Appius Claudius commanded the land forces, and himself the fleet, which consisted of sixty galleys of five banks of oars, full of all sorts of arms and massive weapons. The consul Appius stationed his army round the Scythian portico, from whence the wall was continued along the shore to the mole of the harbour: he employed a great number of artificers for five days to prepare everything necessary for the siege; but, according to Polybius, he had not calculated upon the great skill that would be opposed to him, nor had he considered that the mind of a single man on some occasions was far superior to the force of many hands. Syracuse was a place of great strength; the wall that encompassed it was built upon lofty hills, whose tops, hanging over the plain, rendered all approach from without difficult. Towards the sea such a quantity of instruments for defence had been contrived by Archimedes, that the besiegers were baffled on all sides. Appius, however, with his blinds and scaling-ladders, advanced towards that part of the wall which was joined to the hexapylum, on the eastern side of the city, and at the same time Marcellus directed his course towards Achridina, with his fleet filled with soldiers armed with bowstrings and javelins, in order to drive the enemy from the walls.

There were eight other vessels, from one side of which the benches of the rowers had been removed, from the right side of some, and the left of the others. These vessels were joined in pairs and rowed by oars on opposite sides, and in them were placed machines called sambucca or sackbuts. These machines contained a ladder about 4 feet in breadth, and of a height equal to the walls against which they were to be raised. On either side was formed a high breastwork or tower. The ladder was laid at length upon the sides in which the two vessels were joined, but extending far beyond the prows, and at the top of the masts pulleys were fixed with ropes. At the proper time ropes were attached to the top of the machines, and while some, standing on the stern of the vessels, drew the ladder up by the pulleys, others at the prow at the same time assisted in raising it with levers. The vessels being then rowed near the shore, they endeavoured to fix the machines against the walls. At the top of the ladder was a small stage, guarded on three sides by blinds, and containing four men, who, engaging with those upon the walls, were to endeavour to make fast the machine, and when fixed, these men, being raised above the top of the wall, threw down the blinds on either side, and advanced to attack the battlements and towers. The rest at the same time ascended the ladder without any fear that it should fall, because it was strongly fastened with ropes to the two vessels.

This machine was called a sackbut, because it resembled that instrument when it was raised.

Archimedes was prepared to meet the attack made by the Romans, and while the vessels were at a distance, he employed against them catapultæ and balistæ of enormous size, worked by powerful springs, which discharged darts and stones, throwing them into great disorder. When the darts passed beyond them, and the vessels came nearer, he used other machines proportioned to the distance. Thus repulsed, Marcellus gave over till the night arrived; but when the vessels again approached, they were exposed to new danger from another invention of Archimedes. He had made openings in many parts of the wall, equal in height to the stature of a man, and a palm in breadth, and having stationed archers on the inside, and small scorpions, he discharged such a multitude of arrows through the holes, as to disable the soldiers on board.

When they again attempted to raise the sackbuts, there suddenly appeared above the walls other machines which he had caused to be raised along the whole length on the inside, and which were concealed from view: these stretched their long beaks far beyond the battlements, and many carried masses of lead, and stones of ten talents in weight. When the vessels approached, the beaks were turned by means of ropes and pulleys, and then let fall their stones on the sackbuts and vessels below, and all attending them were thus thrown into the greatest danger. The combatants upon the prows of the vessels were all forced to retire from the discharge of the darts through the openings in the wall, or from the large stones thrown down upon them.

One of the inventions of Archimedes on this occasion was a large iron hand, hanging by a chain from the beak of a machine, which was thus applied: — the beak was guided like the gib of a crane, over the prow of a vessel, and then the hand or grapple was let fall, which attached itself to the prow; the opposite end of the gib was pulled down on the inside of the wall, and acting then on the principle of a lever, raised the vessel on its stern, when the chain was suddenly loosened by means of the pulleys, and the vessels were some

thrown on their sides, some bottom upwards, and others sunk, and as Marcellus jestingly observed, "his vessels were treated as buckets to draw water."

Appius was also obliged to abandon his designs on the land side, for similar obstacles prevented his success: the iron hands or grapples were employed here to lift men with their armour into the air, and then dash them against the ground. So wonderful seemed the power of this one *eminent engineer*, that they were obliged to withdraw their forces, and at last attempt to destroy the city by famine: the place was closely blockaded, and all supplies of provisions cut off both by sea and land.

Archimedes, who was the greatest mechanic among the ancients, was born at Syracuse, about 290 years before the Christian era, and was nearly related to Hiero, the king of that city. He was educated in the sciences of his native country, and afterwards travelled into Egypt, which had been for centuries the resort of many of the Grecian philosophers. Here he remained for several years, and probably became acquainted with the combinations of the mechanical powers, which enabled him to produce the wonderful machines he afterwards used; for in Egypt the lever was applied long before his arrival, in lifting and moving masses of stone to heights far greater than is usually supposed. The discoveries of Archimedes in geometry were highly important. In the two books which he wrote upon the sphere and cylinder, he demonstrated that beautiful theorem, that the surface as well as the solidity of any sphere is equal to two-thirds of its circumscribing cylinder, and that the surface of each cylindrical segment, comprehended between planes perpendicular to the axis, is equal to the superficies of the corresponding spherical segment. In his treatise upon the circle, he also showed that the ratio of the diameter to the circumference was as 7 is to 22; this result he discovered by taking an arithmetical mean between the paremeters of the inscribed and circumscribed polygons.

In his treatise on conoids and spheroids, he shows the mutual relation between these solids, as well as to cylinders and cones of the same base and altitude. The solidity of the parabolic conoid, he found, was one-half that of the circumscribed cylinder, or three-fourths of a cone of the same base and height; and that the area of the parabola is four-thirds that of the inscribed triangle, or two-thirds that of the circumscribed parallelogram. He made us acquainted with the properties of the spiral curve, and the method of drawing tangents to it: also that the sector of the spiral is one-third of the circular sector which incloses it, and consequently that a spiral, which has made one revolution, is equal to one-third of the circle in which it is comprehended.

The fundamental properties of the lever are fully given in his book De Equiponderantibus, or Isorropica: he there proves that a balance with unequal arms will be in equilibrio if the two weights in the opposite scales are reciprocally proportional to the arms of the balance.

He shows also that the fulcrum sustains the whole weight, and that there is the centre of pressure or gravity, and that this centre of gravity is to be found in the parallelogram, triangle, trapezium, or parabola.

His treatise De iis quæ Vehuntur Influido contains the principles upon which the science of hydrostatics is founded: he shows that when fluids are in equilibrium, each particle is equally pressed in every direction: he also inquired into the state of solid bodies floating in water. It appears singular that it should not have been previously known that the weight a body lost when floating in water, was only counteracted by the upward pressure of the liquid.

Archimedes was a man of wonderful sagacity, and laid the foundation of all the sciences, the prosecution and improvement of which are the boast of the present day. He was slain by a soldier during the assault made at the taking of Syracuse, about 212 years before Christ. The ingenious and simple method of raising water by means of a pipe twisted round a cylinder in the form of a corkscrew, and laid in an inclined position with one end immersed in the water, which, when made to revolve about its axis, caused the water to run out at the top, is called the Archimedian screw, and was invented by him whilst he studied at Alexandria, in the school of the Ptolemies.

When this rich and splendid city fell into the hands of the Romans, Marcellus, viewing from a height its beauty and extent, is said to have shed tears. The booty found in it was immense, the royal treasure was carried to Rome, and to the success of Marcellus has been attributed the subsequent degeneracy of the Romans: the statues and pictures which were carried away from Syracuse introduced a taste for the fine arts, and led to that effeminacy of manners which brought about the ruin of the empire.

There remains some part of the temple of Minerva, one of the most ancient in Sicily, of which Cicero gave a very minute description: he describes the doors of gold and ivory, and twenty-seven pictures it contained: it was of the Greek Doric hexastyle, and had fourteen columns on the flank, comprising the outer; their height, including their capital, was 28 feet 8 inches, and their diameter 6 feet 6 inches. There are also two columns belonging to a temple of Diana; and in that portion of the city called Neapolis are the remains of a Grecian theatre, hewn, as they generally were, out of the solid rock. It has three ranges of seats, separated by platforms or galleries, which afforded access to them:

the proscenium is entirely destroyed, and the lower seats are buried: from these ruins the most delightful prospect is obtained of the luxuriant plains below, watered by the Anapus. The steps are perfect in many places, and there is also a portion of the covered portico, or loggia, which surrounded the upper part of this once superb edifice.

Beyond is an amphitheatre of an oval form cut out of the native rock in a similar manner; its longitudinal diameter 316 feet, and its transverse about 214. It was constructed no doubt at the time the Romans became masters of this city. Contiguous is one of those reservoirs for water generally found near an amphitheatre, cut out of the solid rock, and the aqueduct which supplied it: the reservoir is 57 feet long, 23 wide, and 10 feet deep.

The latomiæ or quarries, where the stone was obtained for the various buildings erected in the city, are curious: that near the theatre is about three quarters of a mile in circumference, and excavated to a depth of 120 feet below the level of the adjoining ground: within are many subterraneous grottos cut out of the solid rock, one of which is called the

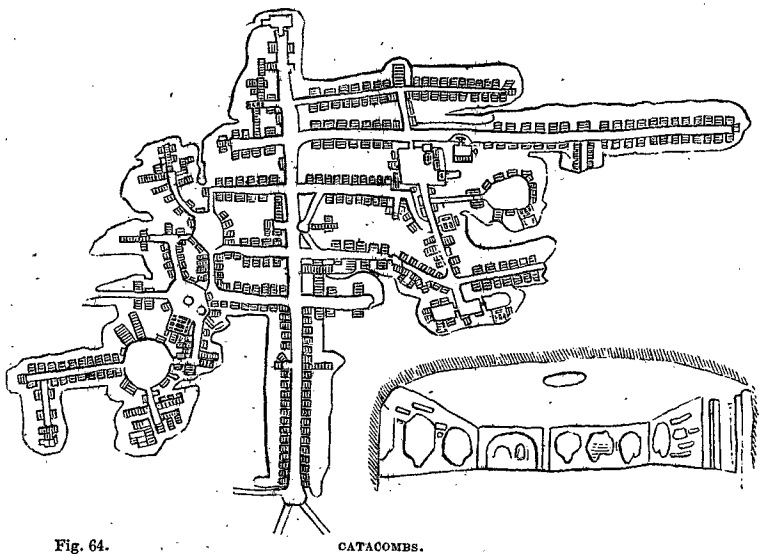


Fig. 64. CATACOMBS.

Ear of Dionysius, it having been formed by him. This grotto is serpentine on its plan, about 170 feet in length, 20 to 35 in breadth, and about 60 feet in height: near the top is a small aperture, which communicates with a chamber 6 feet by 4, said to have been the place where the tyrant resorted for the purpose of listening to the conversation of the prisoners confined within it.

The catacombs, or rather subterraneous city, used for the burial place of the ancient Greek inhabitants, give us some idea of its vast population. The principal street, which passes through them, is 20 feet wide and 8 feet high, and more than a mile in length. On both sides are quarried out tombs, with semicircular headed openings: these formed the sepulchral chambers, and some are admirably worked. Streets at right angles pass from the main line, and here the ceiling takes a dome or spherical shape, in the centre of which is an aperture to admit light and air.

There are many of these catacombs or underground works, cut out of the native rock, to be found along the shores of the Mediterranean; at Malta they extend for a very considerable distance, and appear to have been resorted to in the middle ages by the pious, and dedicated to religious purposes. By some writers their excavation is attributed to the Phœnicians, who were in the habit of depositing their corn and merchandise within them for security when they traded with the native inhabitants. In some instances, as at Paris, these subterranean streets may have been formed by drawing out the stone for the purposes of construction.

Agrigentum, inhabited by a Grecian colony, became celebrated for the refinement of its inhabitants, for the skill displayed in the fine arts, and particularly for the mechanical powers which were employed in raising ponderous masses of stone for the construction of their public buildings: it was situated about 18 stadia or $2\frac{1}{4}$ miles from the sea, between

two rivers, the Agragas and the Hypsa. Polybius thus describes it: — "The city of Agrigentum surpasses most other cities, not only by its fortifications, but also by the

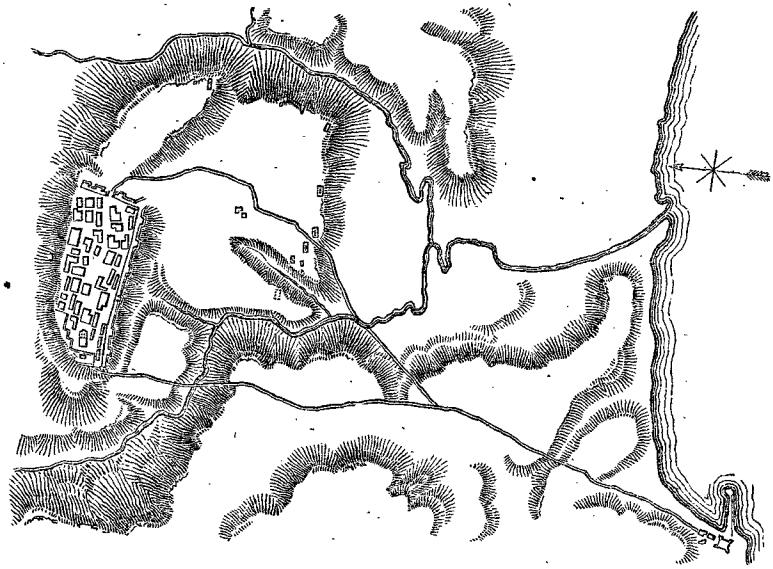


Fig. 65. AGRIGENTUM.

beauty and magnificence of its edifices, and being only 18 stadia from the sea, is abundantly supplied with fish. It is completely fortified both by nature and by art, and its walls are built upon a rock, which forms an excellent foundation; above all, it has been rendered inaccessible by the labours of men, where it was not so of itself. Besides, this city is partly surrounded by rivers, on the south by the Agragas, and on the west by the Hypsa; and on that side regarding the east is the citadel, which is surrounded by a deep ravine. There are erected on the heights of this citadel a temple of Minerva, another of Jupiter; and as Agrigentum was originally colonised from Rhodes, the worship of the god is the same as that of the Rhodians. Among many other things with which this city is enriched, are several beautiful temples and magnificent porticoes; as the temple of Jupiter Olympus, which is the most sumptuous, yielding to none in Greece either in beauty or grandeur.

"Agrigentum was admirably adapted for commerce, from whence it derived all its wealth. Situated on the southern coast of Sicily, it carried on a vast trade with both Tyre and Sidon. Its territory was highly fertile, extending over 1000 square miles, and, according to Diogenes Laertius, this small territory contained 800,000 inhabitants. They exhibited considerable taste in the fine arts, and it was observed by Plato, they built as if they were to live for ever, and feasted as though they were to die on the morrow. It is impossible to account for the great magnificence of this city, where all the merchants were princes. The most flourishing period in its history was comprised in one century, which terminated about 405 years before Christ, when the Carthaginians besieged and destroyed it, at which time, says Diodorus Siculus, the temple of Jupiter was the most considerable on the island, and that when the Agrigentines were on the point of roofing it in, war put an end to their operations: after that the city was so far reduced, that they no longer had the means to finish it."

The length of this temple is 369 feet 6 inches, the breadth 182 feet 8 inches, which by no means accords with the dimensions left us by Diodorus, who gives 340 feet for the length, and 60 feet only for the breadth. In the front are seven columns, and double that number on the flanks, the angles included, — a disposition usually met with in the early Greek temples. The columns are built in a wall, and project a little more than half their diameter: they are 13 feet in diameter, and their projection 7 feet 7 inches; they have eleven flutes; from centre to centre they measure 26 feet 9 inches; from the outer face of the column to the face of the internal wall, which united with it, is a thickness of 15 feet. The height of the steps on which the bases of the columns rest is 14 feet; the base of the column, which is an unusual feature in the Greek Doric, is 4 feet in height; the column, capital, and base

are 61 feet 9 inches in height, the entablature 25 feet 9 inches and the pediment probably as much more: the whole height may have been 100 feet.

The podium formed a magnificent platform for the reception of the temple: it stands upon a native rock raised on solid courses: throughout the whole plan to the level of the

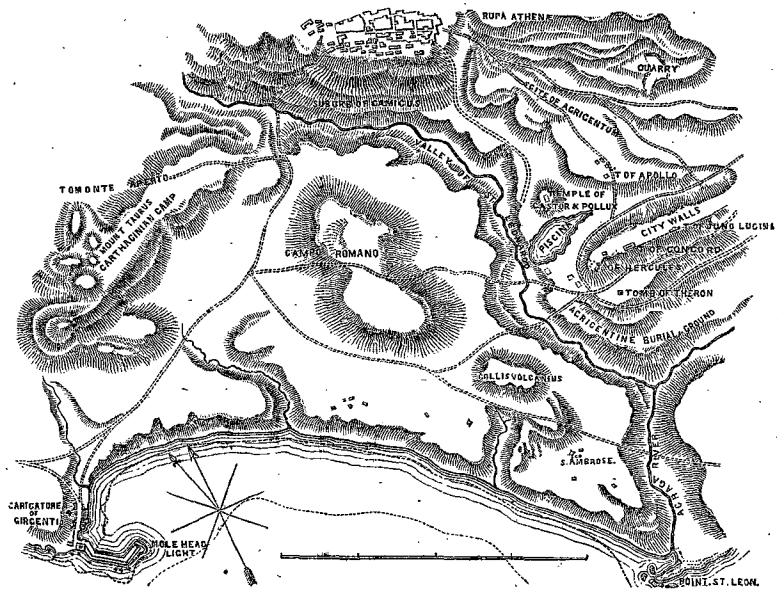


Fig. 66. GIRGENTI.

floor these courses are alternately placed diagonally, and a perpendicular joint separates them from the wall of the peristyle.

The columns are constructed also in courses, with a core alternately circular and octangular; a key or dowel is inserted in their beds; but the writer could find no trace of metal cramps; their diameter is 13 feet; the flutes are sufficiently large, as Diodorus observes, to receive a man within them: the echinus of the capital is formed of two stones only, each weighing at least 21½ tons: these are united by plugs or dowels to the centre stone of the abacus. The abacus is formed of three stones, two of which are 11 feet 9 inches in length, 5 feet wide, and 2 feet 9 inches in depth: the centre stone is 11 feet 9 inches long, 5 feet 9 inches wide, and 2 feet 9 inches deep.

The architrave is 11 feet in height, and is constructed of three courses of stone, each being about 9 tons in weight; the distance from column to column on the lower course is 17 feet 8 inches. It required great skill to construct this portion of the work, and the engineer used all his ingenuity to accomplish it. The two stones forming the lower course are carried on a beam of hard wood, inserted into a dovetailed channel of their soffites, the ends of each stone resting on the abacus, acting as a corbel at the same time.

The triglyphs are all of one stone, weighing 12¼ tons each; the metopes are composed of two stones: on each side of the triglyphs remain the square holes which sustained the scaffolding. Each end of these large stones had channels cut in them of the form of a horse-shoe, into which the ropes were placed, by which they were raised, for the stone was too soft in its quality to permit the use of either the lewis or the forceps. These triglyphs are 10 feet 2 inches in height, 5 feet 10 inches in width, and 4 feet 10 inches in thickness. In the small portion of this temple remaining, parts of four distinct giants are to be seen: built up in courses, each composed of twelve, alternately solid, divided by a vertical joint down to the legs, and occasionally connected with the pilaster behind them; their height was about 25 feet when entire.

The temple to Jupiter was a compound of two others, or pseudo-peripteral, the peristyle being formed by columns inserted in the walls of the naos; the columns of the east and west fronts were probably insulated as Diodorus expressly mentions porticoes. On the pediments were sculptured the war of the giants, and the siege of Troy: it was

called the temple of the giants, from having figures in the manner of Caryatides supporting some part of the edifice. According to Diodorus Siculus, it was the largest temple in Sicily, and might be compared with the grandest and most magnificent monument that ever existed.

Not far distant from the ruins of this temple, are the remains of the famous Piscina, which, according to the same writer, was 7 furlongs in circumference, and 20 cubits in depth: the water was conducted into it from the neighbouring streams: this was probably executed by Pheaces, under whose direction were made the several *sewers* which carried off the water from the city, and which were afterwards called by his name; he lived in the time of Gelon, or about 500 years before Christ. These sewers, therefore, were subsequent to the great Cloaca at Rome.

This city was surpassed by few in the beauty of its temples, and for the luxuriance of the country around: there are the remains of a temple to Hercules, Castor and Pollux, Juno Lucina, and Concord, all in the style of the Greek Doric. The modern town of Girgenti is near the ancient mole.

Selinus was founded about 725 years before Christ, 107 years after Syracuse; and took its name from the river Silenus. Its first inhabitants were a colony from Megara, a city on the eastern coast of Sicily, which was called Megara of Attica, from whence its inhabitants migrated; 250 years after its foundation it was besieged by Hannibal, carried by assault, the citizens put to death, and the walls of the city rased to the ground. Soon after this, Hermocrates repaired the walls, and assembled many of the wandering natives who fled before Hannibal's army had arrived in the neighbouring states. It became again a place of importance, and the temples, which had only been robbed of their treasures, remained until a second siege by the Carthaginians, when they were thrown down; the city was then abandoned, and Strabo enumerates it among the ruined cities of Sicily. The great quantity of fallen stones which here present themselves lead us to fancy the buildings must have been the work of giants, as, from the enormous size of some of the blocks which composed them, it does not seem possible that they should have been moved by men.

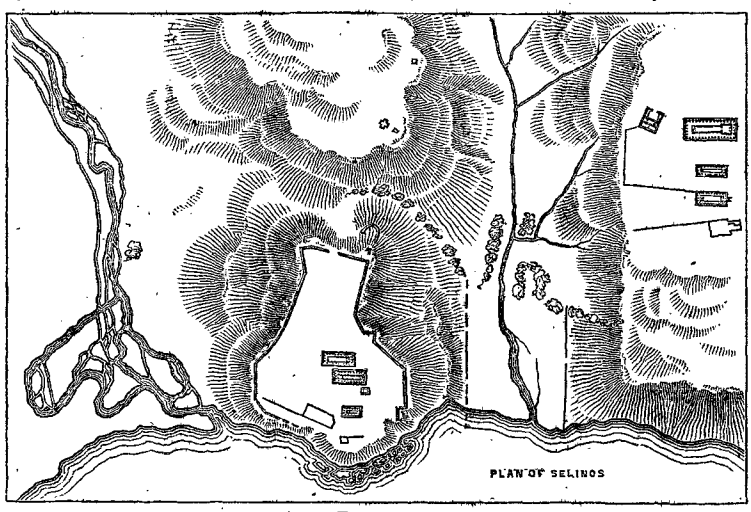


Fig. 67.

The plan of the city, which is traceable from the existing walls, is somewhat in the shape of a horse-shoe, whose two ends are towards the sea: these were terminated by towers: the port, which lay between them, exhibits no remains. On the western side, the walls are quite perfect, as are also two vast flights of steps, by which the inhabitants ascended from the port to the city. The time when the six temples were thrown down, and the means by which their ruin was accomplished, is unknown: it has been supposed it was the result of an earthquake, as their immense solidity must have defied all human means. The columns of the larger temple have all fallen in one uniform direction, thrown down by one effort; but surely the power which could have raised the immense blocks might also, when applied to their destruction, be competent to produce this effect.

All these temples were of the Greek Doric order; some of the blocks of stone used in their construction were immense; one, which formed the architrave of the greater temple, supposed to be dedicated to Jupiter, is 21 feet in length 5 feet 8 inches in width,

and 6 feet 9 inches in depth, containing 803 cubic feet, weighing probably 50 tons. The manner adopted by the ancients to lift such a ponderous mass, and place it safely upon the capitals of columns, upwards of 40 feet from the ground, deserves our highest admiration.

Most of these temples, like others of the best periods of Greek architecture, were painted, either entirely or in part; the Egyptians and the Etrurians probably set this example. On sandstone, which had not an even surface, previous to painting, they spread a coat of fine plaster or calcareous composition: the metopes of one of these temples, of a very early date, are painted red, blue, and green; some of the parts were also gilt; and we find similar vestiges in the temples at Athens and elsewhere.

Ægesta, according to Cicero, was founded by Eneas, after he fled from Troy. It has always been considered one of the most ancient towns in Sicily. This city survived many vicissitudes of fortune, and retained its importance till the Saracenic conquest, when it was almost destroyed. The temple that remains is situated to the east of the ancient city, placed upon the brow of a craggy precipice: the solidity of its construction as well as simplicity of its architecture, have occasioned it to be classed among the earliest existing monuments of Sicily. The stylobate consists of three steps, the upper of which is tooled perpendicularly: each stone forming these steps has a knob projecting, similar to those in the Propylea at Athens, probably left to afford facility in raising them. The temple is hexastyle peripteral, has fourteen columns in the flanks, including those at the angles: the columns, unlike all others, are not fluted, although it was not unusual to work such portions after the buildings were constructed. There is no part of the cell remaining: the total length is 190 feet, and width 76 feet 8 inches. There are considerable ruins of a theatre, which has some stones in its construction of an enormous size: it is erected upon a very irregular surface, partly resting on the native rock, and partly on stone piers and solid walls: there is no vestige of an arched corridor, but the seats are placed upon solid masonry: part of the proscenium wall as well as many of the ancient steps remain.

At *Taorminum* is a similar theatre, which, from its fine state of preservation, is worthy of being studied. The Greeks seem to have found a situation where little was required to be done but to excavate the seats out of the native rock, and then erect the exterior and interior portico which surrounded it. This theatre stands upon an eminence overlooking the sea, almost entire; all that is not excavated out of the rock is formed with brick, and the columns with which it was adorned were of marble, probably from the neighbouring quarries. The summit of the mountain is of the shape of the portico which surrounds the theatre, and formed a beautiful promenade: its site is precisely what Vitruvius recommends, being elevated, and well calculated to convey the sound. The spectators ascended the rock to the level of the portico by means of several staircases, then entered the theatre, and descended to their seats. In the interior face of the wall which surrounds the theatre are niches, which originally contained statues.

The interior, with its orchestra, pulpitum, and proscenium, partly remains: the pulpitum was ordinarily formed of wood supported by walls, and here such foundations are still apparent. The proscenium had three doors or entrances, were called aula regia, and aulæ hospitalia. Some magnificent views of this theatre, made by Lusieri, were forwarded to England some years ago, and are deposited in the British Museum.

Messina stands upon elevated ground, at the extremity of a range of mountains which runs through Sicily. There is a broad modern quay, where vessels of almost any burden may lie close in deep water. At the western extremity is a small fort and a gate: the other end is closed by the citadel, which is a pentagonal structure, standing on the isthmus of San Raniero: near this is the Lazaretto. The entire circumference of the port, which is in the form of a sickle or zancle, is about 4 miles, and is said to owe its formation to the effects of an earthquake, which opened a chasm, afterwards filled with water, upwards of 70 fathom in depth.

Near the lighthouse is the pool Charybdis, formed by the crossing, or rather meeting, of many opposite currents.

The first inhabitants of this celebrated port were the Siculi, driven out by the Cumæans; who in their turn gave way to the Samians and Messinians.

The straits which divide Sicily from Calabria are so narrow, that small fishing boats alone are employed to convey the inhabitants from one side to the other; and many instances are said to occur in which individuals swam across. St. Francis, in modern times, is reported to have spread his cloak upon the waters, and with one end raised upon his staff, to have thus passed from one shore to the other.

From the contiguity of Messina to the coast of Italy, it has at all times enjoyed considerable commerce: here landed the Normans under Maniaces when Sicily cast off the yoke of the Arabian conquerors in the year 1037; but within the present city there is little remaining to indicate the Norman sway; there are no vestiges of either of the two churches or other buildings completed by Count Roger — though in the crypt of the cathedral may be seen some parts of the work of his son, afterwards king. Richard Cœur de Leon, assisted

the renowned Roger again to expel the Mahometans, and wintered here on his way to Palestine.

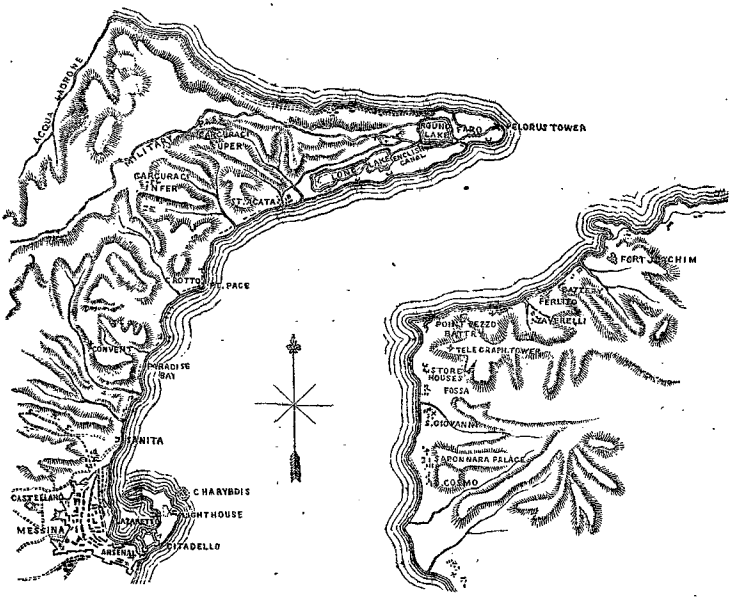


Fig. 68. MESSINA.

Posidonia, or *Pæstum*, was happily situated both for the purposes of agriculture and commerce, placed in the midst of a plain, bounded by the rivers Silarus and Accius on the north and south, sheltered on the east by the mountain Alburnus, and open to the bay on the west. The port Alburnus was near the mouth of the Silarus, and some remains of it may still be traced; it was frequented by merchants of all nations. Strabo tells us the original inhabitants, driven out of Sybaris on the shores of Tarentum, crossed the Apennines, and settled in the plains of Posidonia. The Sybarites soon made their new town both important and powerful; for two centuries they continued in a state of perfect tranquillity, which was at last disturbed by the tyrant Dionysius of Syracuse, who invaded the Grecian territories established in Italy: he afterwards, uniting with the Lucanian aborigines, gained several victories, and Posidonia fell, about the year of Rome 413. Seventy years afterwards it was made a municipal town, and its name changed to Pæstum.

From the neglect of proper cultivation and the drainage of the marshes, the stagnant waters, emitting pestilential vapours, obliged the inhabitants to seek a new situation.

The walls which surrounded this city remain to a considerable height in many places, as do the towers at the angles, and the ancient gates: its form is that of an irregular polygon, about 3 miles in circumference.

There are three temples, an amphitheatre, and some other buildings. One of the temples, supposed to have been dedicated to Neptune, possesses in a high degree all the characteristics of Greek architecture: solidity, combined with grace and simplicity, prove it to have been erected before the arts were on the decline. The stone used for its construction, as well as for that of the other buildings, was brought from quarries in the mountain Alburnus: it is a stalactite formed by a calcareous deposit, of the same nature as travertino. A thin coat of stucco was laid over the whole to fill up the interstices of this porous stone.

The form of the temple dedicated to Neptune was hexastyle, with fourteen columns on the flanks, counting those at the angles: the upper step of the stylobate was in length 195 feet 4 inches, and its breadth 78 feet 10 inches: the columns are 6 feet 10 inches in diameter, and 29 feet in height, including the capitals, while that of the entablature is 12 feet 2 inches. This temple was probably hypethral, as there are two inner rows of columns, above which is another of less dimensions which supported the roof. Those of

the lower range are 4 feet 8 inches in diameter, and 19 feet 9 inches high, and the upper have their shafts in accordance with the upper diameter of the lower order.

The second temple, or Basilica, as it is sometimes called, is pseudo-dipteral, has nine columns in the front, and consequently three columns placed between the antæ; thus differing from all other examples.

A range of columns passed through the middle of the cell longitudinally, probably to support the roof. Its length, measured on the upper step, is 176 feet 9 inches, and its breadth 80 feet: the diameter of the columns is 4 feet 10 inches, and their height, including their capitals, 21 feet: the shafts diminish in a curved line, and are channelled with twenty flutings. The entablature is not perfect, but the frieze was composed of two upright courses of stone, the exterior one of which, with the whole of the cornice, is gone. The lesser temple is hexastyle-peripteral, with thirteen columns on the flanks, counting those at the angles: its length, measured upon the upper step, is 108 feet, and its breadth 48 feet. The columns are 4 feet 3 inches in diameter, and their height, including their capital, 20 feet 6 inches; they are about a diameter apart all round; they have 24 shallow flutings, and were placed upon circular bases slightly projecting.

Bridges of the Greeks. The Gephyreans, who inhabited Eretria, formed a part of that body of Phœnicians which, according to Herodotus, Cadmus brought with him into Greece, and were acquainted with science as well as letters. When the Cadmeans were expelled by the Argives, they fled to the Encheleans, and the Gephyreans were driven by the Bœotians to find succour at Athens. They settled on the borders of the Cephissus, a small river which separates Attica from Eleusis, and here they are said to have built a bridge. Larcher, in his notes upon the above passage of Herodotus, observes that the author of the Etymologicum Magnum pretends that these people were called Gephyreans in consequence of their constructing this bridge; Gephura signifying originally a dam, dyke, or mound; also the space which occurred between two hostile armies in Homer; but generally it is significant of a bridge in other authors. Pindar uses *Pontou Gephura* for an isthmus. The origin of the compound word was Gea, *earth*, and Phero, *I bear*, as affording a passage from bank to bank.

In another passage in Herodotus we learn that when Crœsus passed the river Halys with his forces, it was by means of bridges, although the Greeks generally asserted that Thales the Milesian assisted him in cutting another trench for the purpose of dividing the river, and that then he was enabled to ford it readily; it being much less labour to divert the waters of the river than to build a bridge.

There were in Greece few rivers which might not have been rendered fordable, and it seems probable that the usual method adopted in early times to pass a river, was by throwing in stones or earth to form a dyke or dam, which would occasion the water to become sufficiently shallow for the passage both of men and cattle. Fords could be more easily contrived than bridges, and it is certain that the latter were not much used by the Greeks. When Darius had resolved to make an expedition into Scythia, he prepared a fleet, and ordered a bridge to be thrown over the Thracian Bosphorus. Gibbon observes, that the most skilful geographers that have surveyed the Hellespont give sixty miles as the length of its winding course, and about three miles for the ordinary breadth. But the narrowest part of the channel is found to be northward of the old Turkish castles, between the cities of Sestos and Abydus. It was here that the adventurous Leander braved the passage of the flood, and where the distance between the opposite banks does not exceed five hundred paces. Xerxes imposed here his stupendous bridge of boats for the purpose of transporting into Europe his 170 myriads of barbarians.

Herodotus says the breadth of the Bosphorus where the bridge was erected was 4 stadia, and that Darius was so much delighted with its construction, that he made many valuable presents to Mandrocles, the Samian, who constructed it. Mandrocles, in consequence, caused a representation of the bridge, and the king seated on his throne reviewing his army as it passed, to be made, which was consigned to the temple of Juno, where it remained for some time.

After Darius crossed into Europe, he ordered the Ionians to pass over the Euxine to the Ister, to erect another bridge, and await his arrival.

When Xerxes passed the Hellespont, 480 years before Christ, numbers were employed in constructing a bridge betwixt Sestos and Madytus, in the Chersonese of the Hellespont; and the work was commenced on the side next Abydus. The Phœnicians in his army used a cordage made of linen, and the Egyptians the bark of the biblos; and this bridge, which is briefly mentioned by Herodotus, was no sooner completed than destroyed by a tempest. Whether made of boats or floating timber, we are not informed. After this a bridge was constructed by different architects, who performed it in the following manner: — they connected together ships of various kinds, some long vessels of fifty oars, others three-banked galleys, to the number of 360, on the side towards the Euxine Sea, and 313 on that of the Hellespont. The former were placed transversely, but the latter, to diminish the strain of the cables, in the direction of the current, when these vessels were secured on each side by anchors of great length; on the upper side, because of the winds which set in from the Euxine; on the lower, towards the Ægean Sea, on account

of the south and south-east winds. They however left openings in three places sufficient to afford a passage for light vessels, which might have occasion to sail into the Euxine or from it. Having performed this, they extended cables from shore to shore, stretching them from large capstans of wood; the cables being made of white flax and biblos: two of one being united with four of the latter, they were alike in thickness, but those made of the flax were the strongest, and every cubit in length weighed a talent.

After the boats were fixed, large timbers were laid across the cables, and bound fast to them; these were floored over, and a platform made in the usual way, upon which was placed a layer or stratum of earth, and a fence raised on each side to prevent the horses looking down into the sea.

Polybius, in alluding to the first bridge built by Darius, says that the width of the strait between Sestos and Abydus was not more than two stadia, that both shores were covered with inhabitants, and that they sometimes threw a bridge across the strait and passed from one side to the other on foot; at other times vessels were seen sailing upon it; and also that the city of Abydus was enclosed by the promontories of Europe, and had a safe harbour, in which ships might be sheltered from every wind; but that at its entrance it was not possible for a vessel to anchor, on account of the violence with which the waters rushed through the strait.

Cyrus is said by Xenophon, when he marched from Sardis, after passing through Lydia, to have crossed the river Mæander, where it was two plethra in breadth, by a bridge supported on seven boats. Supposing this distance to have been 200 Greek feet, it would not have been difficult to throw a timber platform from one boat to the other, and make a substantial roadway.

The usual method of crossing rivers is perhaps that described by Xenophon in his march through the desert, when he came to Carmande on the Euphrates: here the soldiers purchased provisions, and afterwards passed over the river on rafts, made by filling the skins they used for their tents with dry hay, and sewing them together, so that the water could not enter. The Roman soldiers, as well as the Greeks, made their tents of skins; and we learn that Alexander, in his victorious march through Asia, used this method of crossing a river. In this manner he passed the Oxus, which was a wide, deep, and rapid stream; and Arrian informs us that this passage occupied five days.

The *Mole*, which united Chalcis in the island of Eubœa with Aulis in Bœotia, is described by Diodorus Siculus as formed over the Euripus, the name of the straits that separated the island from the mainland. When Mindarus, the commander of the Peloponnesian fleet, arrived at Abydus, and had repaired his shattered boats, he sent for succour to the Lacedemonians, determining to lay siege to the Athenian cities in Asia. The Chalcedonians and the inhabitants of the island of Eubœa, at that time had deserted from the Athenians, and the latter were greatly alarmed from fear of an invasion, the Athenians being the masters of the sea: they therefore solicited the Bœotians to help them to stop up the Euripus, and attach the island to the continent. In this narrow strait the sea was supposed to ebb and flow seven times in twenty-four hours, and Aristotle destroyed himself because he could not ascertain the cause of this phenomenon. The Bœotians readily consented, as it would make Eubœa part of their continent. All the people that could be assembled took part in this great work, and commenced a mole at Chalcis, and another at Aulis, on the Bœotian side; and each was advanced over this unquiet, and then raging passage of the sea, until the way was so narrow that there was only room for one ship to pass; after which forts were constructed, and a wooden bridge thrown across the opening.

The port of Aulis would at one time contain fifty ships, and was famous for its manufacture of pottery; the opposite port, which is now the town of Vathi, is completely landlocked, which accounts for the extreme narrowness of the Euripus itself, now crossed by a wooden bridge: this leads to a Turkish fort, then a marsh, where is another wooden bridge, which conducts to Negropont.

Walls of cities. There can be no doubt, that in the primitive ages of society, security was one of the chief considerations, and that no exertion was spared by any of the nations of antiquity to carry up works of defence. Throughout Greece are remains of cities, where we have evidence of the labour bestowed upon the walls, which, when in a complete state, were regarded as the performance of persons something more than human.

The walls of Tiryns and Mycenæ are perhaps the most ancient and the most celebrated. Homer mentions the former, a proof of their existence in his time: they are said to have been constructed by a colony of Lycians, under the direction of Prœtus, the brother of Acrisius, long before the Trojan war. The city of Tiryns occupied a rising ground in the plain of Argos, and was of no great extent, being 220 yards in length and 60 in breadth, according to Pausanias, it was founded by Tirynthus, the son of Argus, who employed the Cyclops to construct the walls: these were built of large masses or blocks of stone, each requiring two oxen to move it: after one was placed, another was brought, and laid adjoining, the interstices being filled up with fragments and

smaller stones to render the work more solid. Some of these masses measure more than 9 feet in length, 4 feet in breadth, and as much in thickness. It had three gates, the chief flanked by a solid tower, which could only be ascended by a flight of steps running parallel with the wall for some distance, and afterwards turning at right angles, before it reached the gate.

Euripides is among the first who designates the construction with polygonal blocks, Cyclopean; they were probably the work of the Pelasgi, who were the earliest inhabitants of Greece of which we have any account. These people may be traced throughout every part of Greece, Peloponnesus, Thessaly, Attica, Bœotia, Phocis, Macedonia, and even at Delphos, where the oracle was Pelasgic. Dardanus, the ancestor of Priam, was of this race.

The Pelasgi remained in possession of Arcadia until the second Messenian war; and they were finally expelled, or conquered, throughout Greece, it is supposed, at a considerable time before the Trojan war. After their expulsion the Hellenes were established; Danaus founding Argos; Cecrops, Athens; and Dardanus, the Phrygian cities. Diodorus allows the Pelasgi, however, to have retained dominion at sea, from 1088 to 1004 years before Christ; they are said by Dionysius to have finally settled in Italy at an earlier period, and that they began to decline about 1170 years before Christ.

In the most ancient part of the walls of Tiryns there is, for the length of 90 feet, a gallery, supposed at one time to have continued through the whole circuit of the external walls, which must have been of great advantage to the inhabitants in the defence of their city. It is 5 feet in width and 12 in height, formed of large stones, laid in horizontal courses, gathered over towards the top, where they incline against each other, thus presenting in the section of the gallery the form of a pointed arch. At every 9 feet distance is contrived a recess, to retire during the time it was required for another to pass. Undoubtedly this is one of the earliest examples of a practice afterwards universally adopted both by Greeks and Romans.

The walls of Tiryns were destroyed, according to Pausanias, for enlarging Argos; what remains is upwards of 43 feet in height, though originally much higher.

Mycenæ, in the neighbourhood of Tiryns, far exceeds it in extent: according to Pausanias, it was founded by Persicus, and the circuit of its walls followed an irregular line, enclosing an area, in length about 330 yards, and in breadth 220 yards.

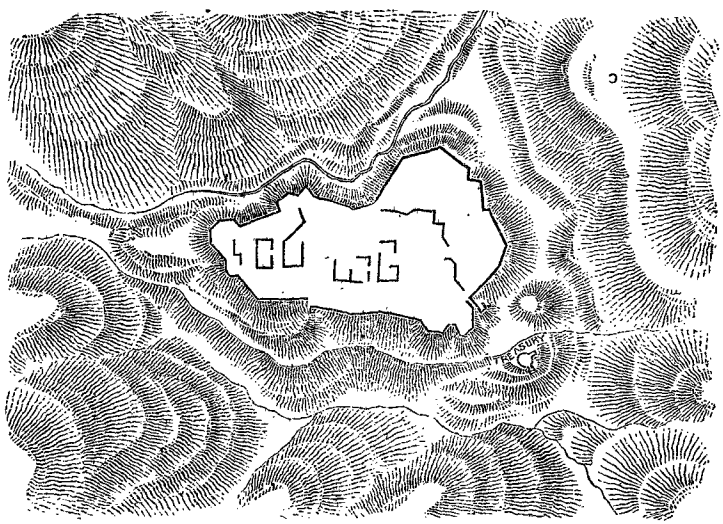


Fig. 69. MYCENÆ.

The walls consist of polygonal blocks, so large and solid, that they have defied the destruction offered both by time and by the hand of man. The Argives commenced the destruction of this city about 468 years before the Christian era; but they could not break down the whole of the walls, the stones being so firmly united together. The blocks with which they are built, on the outside present a fair and even face, and their

ends and sides are fitted to each other. And there are evidences that stone-cutting was now adopted. No mortar or cement was made use of; the massive blocks received their

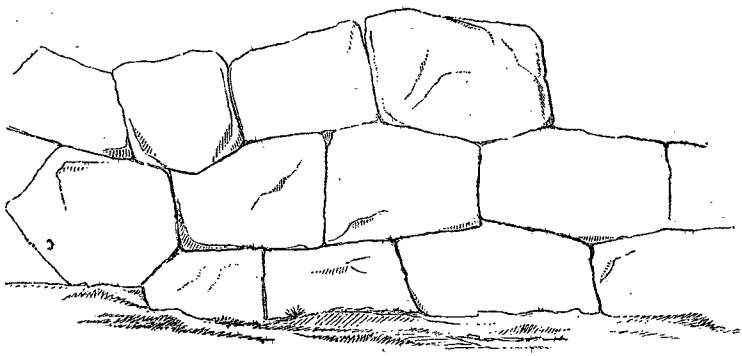


Fig. 70.

stability from the manner in which they were wedged in, many passing entirely through the whole thickness of the wall, and bonding it together.

On the north side of the acropolis may still be seen remains of the walls built by the Pelasgi, and which are usually denominated Cyclopean.

The sites of these early Greek cities were generally chosen upon rising or elevated ground, and the form of the hill or eminence usually decided that of the city. On the highest ground was placed the acropolis or citadel: such was the method adopted in setting out Athens, and, where the wall made an angle, it was sometimes further strengthened by throwing out some additional work, which may have led to the introduction of towers.

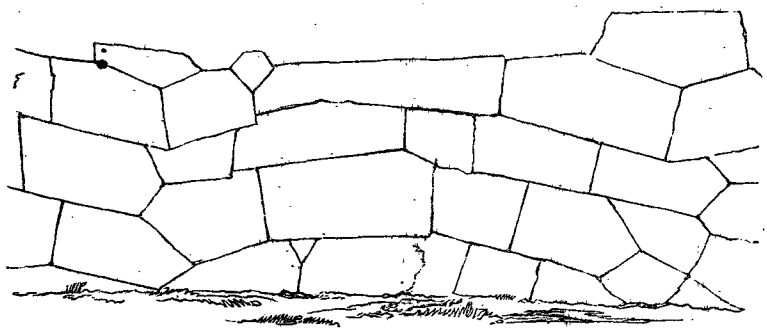


Fig. 71.

Gates or entrances to the Greek cities were of four different kinds: the earliest and the most usually found, perforating their ancient walls, had its sides perpendicular, and the opening above closed, by the polygonal blocks advancing until they met in the middle at top, like the gallery at Tiryns; there are many remains of this kind of gate, as that at Signa. (See *fig.* 74.)

In the Isle of Delos is another of great antiquity, which is formed by the inclination of stones resting one against the other. (See *fig.* 57.)

This very curious remain forms the part of a gateway, or opening, through the walls of an ancient fortification, around the lower part of the mount Cynthus. Ten large stones, inclined towards each other, form the covering to the opening, and very much resemble some of the examples met with in the pyramids, where the weight over the passages and galleries is discharged in a similar manner. Should this portion of the walls be as early as the time of Minos, we must consider that he employed the same construction as the Dorians, or Cyclopeans as they have been called.

Delos, after having been the abode of pirates, was converted into a colony of Athens by Erysichthon, son of Cecrops, who erected the first temple to Apollo, afterwards held in such high veneration by all the Greeks, and even respected by the Persians, who laid waste

most of the other islands in this sea. Pericles, according to the historian Thucydides, seized upon the treasury established here by the states of Greece, which amounted to 10,000 talents, for the purpose of defraying the expenses of erecting the Parthenon at Athens.

Mount Cynthus was the birthplace of Apollo and Diana, and from hence the Hyperborei, or most northern people of antiquity, transmitted annual offerings. The altars at Delos were circular; it being the custom for the votaries of Apollo to run around and strike them with whips, their arms bound behind them at the same time: they afterwards bite the olive, which was a symbol of the motion of solar light, and of their desire that its rays might pervade all space.

Numerous fragments of architecture and sculpture are met with in this favourite island; among them, heads of bulls arranged on the entablature in a similar manner as found at Persepolis, which might allude to the worship of the celestial bull, or the sun when occupying the place of that sign. Before Zoroaster reformed the Persian worship, under the auspices of Darius Hystaspes, such emblems were common, and formed part of the Mithraic ceremonies in Persia; and even among many of the Cyclades under Persian rule, where the religion of the Magi had not been received.

The second sort was like the gate at Arpino; an opening in the form of a lofty pointed arch, which, from its being inconvenient for the reception of a wooden door or entrance, could only be closed by rolling into it a large stone, or entirely walling it up. (See *fig.* 72.)

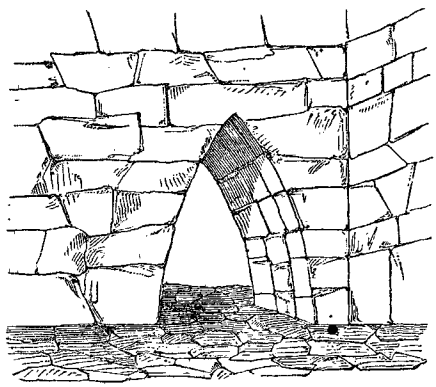


Fig. 72. ARPINO.

In this example we have the form without the principle of the pointed arch; the stones overhang like corbels, and are not radiated to their respective centres: after the form was given, probably the setting out of the voussoirs according to the right principle followed.

In many parts of Greece we find openings in the walls so arranged, and the weight over them similarly disposed; this system led to the practice adopted in the conical structures, where a series of concentric rings, gradually diminishing, have the same support as this system of corbelling or gathering over. Walls constructed of regular masonry, and afterwards perforated or cut through, would present such an aperture in the course of a short time; the different courses would chip off till something like the form of the equilateral triangle was assumed, which, if assisted by a little art, would give the rudiments of a pointed arch. Where such was the result of undermining or a settlement, the stone would incline at the heading joints, and the principle of an arch would be partly developed.

When the writer refers to the sketches he made in his tour through Greece, he finds abundant examples of openings through walls or entrances, formed by the mere taking out of stones, originally laid in the Cyclopean manner; some of these exhibit the arch entirely. In *fig.* 71. the lower course might be removed, and a segmental figure obtained, the stone work above remaining unaltered: the mere observance of such an accident would lead to a knowledge of the arch, and show that superincumbent weight might be safely discharged. To minds possessing the acuteness of the Greeks, such an accidental circumstance would not be lost, or the lesson taught thrown away; when once the wedge theory was taken up, there can be little doubt but the value of pressure on each of the voussoirs of an arch would be practically understood. The rudeness of the examples left by no means implies that others of a more perfect and refined character did not exist; their destruction being easy, may account for our not discovering any remains. No work, which Persian ambition could desire to annihilate, could be more readily destroyed than the abutments of an arch, which would bring into ruin all in connection with it; a bridge, or entrance to a city, had the arch been introduced, could be easily displaced, whilst the rude Cyclopean wall would exhibit difficulties and danger to any attempting its overthrow, the stones being so placed upon and against each other, that the removal of their abutments would not be sufficient for their demolition. It would be required to move each stone in the order in which it was built up.

The example which follows exhibits a third kind of entrance, where a horizontal stone is resting on the side walls to discharge the weight, which could not be applied to very large openings. Such an example exists at Alatri (*fig.* 73.) in a wall of Cyclopean construction, where the courses are irregular, and the perpendiculars not kept.

Where a lintel or stone could not be found sufficiently long to extend from one jamb to another, the upper course on one or both sides required inclining, as in the gate at Signa (*fig.* 74.) where the early Greek construction is adopted; to trace the regular arch from these rudiments is difficult, as we do not discover in any of them the next step by which the process was completed. Among the researches of modern travellers, an account of a

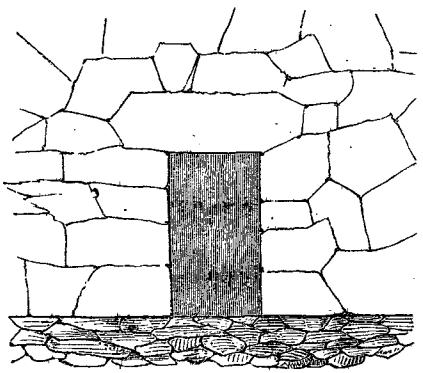


Fig. 73. ALATRI.

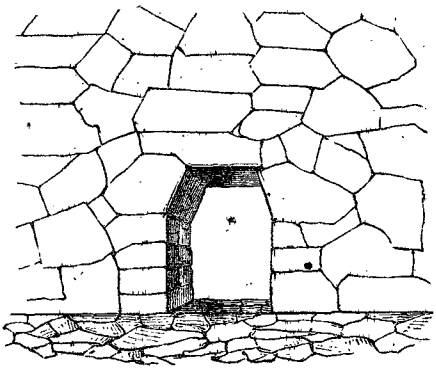


Fig. 74. SIGNA.

perfect arch is not to be found; and the writer looked through Greece for a specimen, in vain. That such a form was unknown to them, can hardly be supposed; but it certainly is curious, that no examples are left us.

By a combination of the second and third kinds, and the introduction of upright posts or jambs, we have a gateway of the fourth sort, of which we find many examples, particularly that called the *Gate of the Lions* at Mycenæ. Pausanias informs us that it existed in his time. (*See fig.* 75.)

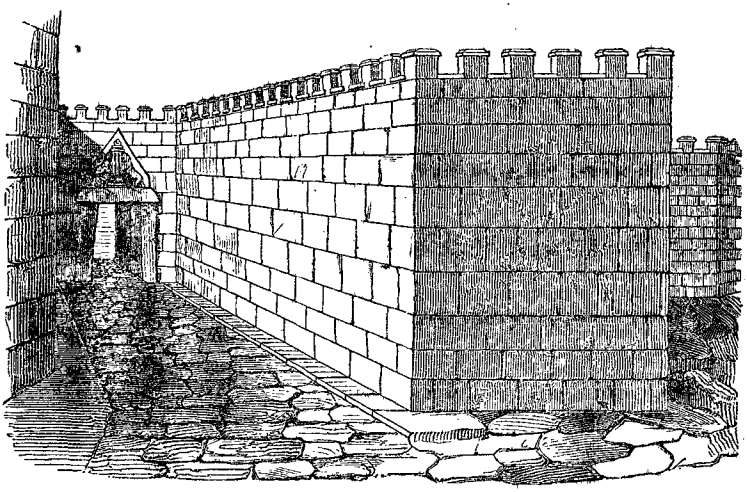


Fig. 75. MYCENÆ.

This gate, like others of the early Greek cities, which formed the chief entrance, is not built in the continued line of wall, but recessed at the end of a narrow passage, at a considerable distance within the outer circuits. This arrangement was undoubtedly contrived for defence, it not being possible for a number to make an approach through this narrow defile at the same time.

This gate is 8 feet in width, and the horizontal stone which serves as a lintel is 12 feet in length; the lions mentioned by Pausanias are cut in relief out of a single stone, 9 feet in height and about 13 in width: it may date as among the earliest works of sculpture in Greece.

Such gates were defended with more ease from their being recessed; at Norma we have another example (*fig.* 76.), which shows more perfectly the method adopted by the Greeks to annoy an enemy whilst attacking them.

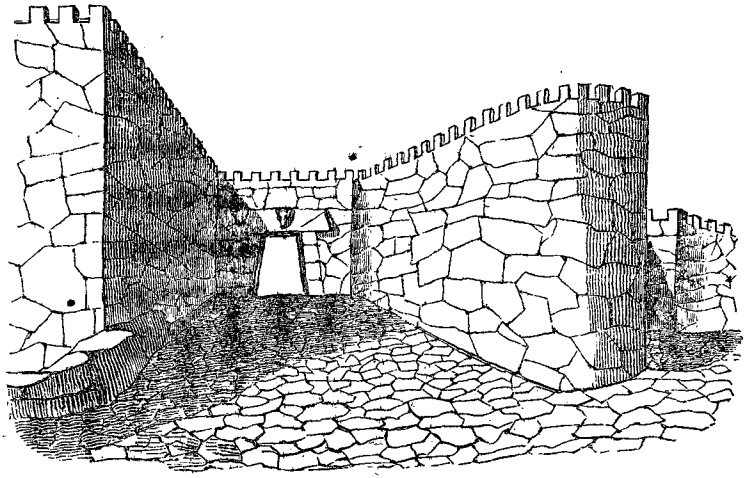


Fig. 76. NORMA.

The Scæan Gate had an advanced mole or wall, carried out for some distance on the left hand on coming out, which was used by the military or guard for the discharge of missiles against those who were attempting to enter without permission. The reason assigned for the left side being preferred, was, that an attacking party would cover their left sides with their shields, and hold their spears in their right hand, which would present to the besieged the only uncovered part that was assailable; consequently, by this arrangement, the right side of the attacking troops became open to the weapons of the besieged, and the darts or projectiles from the wall in advance could be brought fully to bear against the most vulnerable parts of the besiegers.

Delos exhibits an arched gallery, already described, of the same construction as that in the wall of Tiryns, and among the towns in Greece are found many subterraneous passages, like that mentioned by Strabo as existing at Preneste, which was underground, and served usually the purposes of a sewer, conveying the water from the city into a deep valley, and at other times for a sally port.

These galleries or passages were cut in the rock, sometimes in the natural soil, and often mined or excavated like a tunnel through the neighbouring country.

Another description of wall which surrounded the cities of Greece showed an improvement in construction: these had the courses of stone or marble laid in a more regular manner; and to which were added towers of a square, circular, or polygonal form, placed at regular distances. Such were those at Argos, Messene. (See *fig.* 78.)

Messene was a city at the foot of Mount Ithome, and celebrated for the wars carried on by its inhabitants against the Spartans, about 700 years before the Christian era. The Thebans, who under Epaminondas defeated the Spartans about 370 years before Christ, are supposed to have constructed the walls and towers of this city, which remain. Epaminondas, according to Pausanias, being assured that the site of Messene was admirably adapted for a city, desired that the Augurs might be consulted on the subject; and favourable omens being obtained, he commenced the foundations, and ordered the stone to be brought from the neighbouring hills. The Gulph of Messene lies a little distance from the city on the south; to the west spreads Arcadia; and Ithome rises above the plain with Mount Eva to the south. On the top of Ithome are the remains of the citadel.

After the numerous defeats which the Messenians sustained in their contests with the Spartans, Pausanias informs us, they abandoned their other fortified cities, and retired to Ithome, which Homer alludes to —

> And those that on the steep Ithome dwell.

They increased the citadel, and rendered it, by several engineering works practised on the steep rocks, difficult of access. From this place they sent messengers in their distress to Delphos to inquire of the oracle what they were next to do, when they were ordered to sacrifice a pure virgin to the infernal demons. All their efforts, however, were useless in the

battles in which they afterwards engaged; and the inhabitants of Ithome were obliged to seek refuge at Argos, Sicyon, and Arcadia, or Eleusis, and the Spartans razed the citadel to its foundation.

The Messenians, after being continually harassed, at last settled at Rhegium, on that part of the Italian coast opposite to Messina. This event happened about 723 years before Christ. Anaxilas, one of their leaders, took possession of the territory belonging to the Zanclæi in Sicily, where he built a city, and strongly fortified it; and the new inhabitants turned their attention towards maritime affairs. Such, Pausanias tells us, was the end of the wanderings of the Messenians. We can account for the construction and systems adopted for the defence of the cities in Sicily, resembling those met with in Greece, when we learn that their builders were driven out from among the people who occupied the latter country: when they fled, they carried with them a knowledge of the arts, and laid the foundation for their promulgation throughout the new settlement.

The circular court remaining at Messene forms the northern entrance to the city, from whence the route to Megalopolis took its departure. On each side of the entrance are the foundations of two towers which defended this approach.

Around the walls of the circle are two niches or recesses, with square heads, and slightly decorated. The diameter of the circle is 63 feet, and the largest aperture by which it is entered, 23 feet: the other, about 17 feet, was covered by a lintel, the dimensions of which were 18 feet 10 inches by 3 feet 4 inches high, and 4 feet wide: such dimensions required some support from beneath, or the weight should have been discharged from above, that the lintel might have rested securely, without danger of fracture.

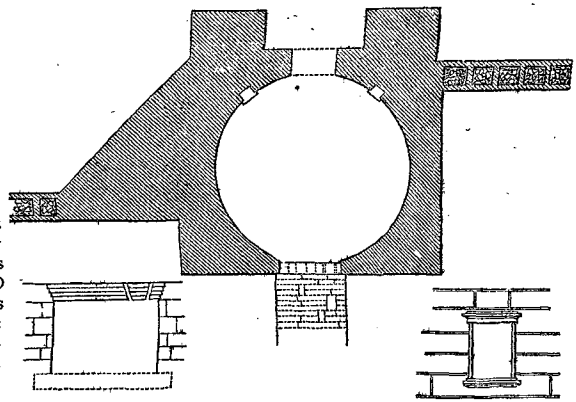


Fig. 77. MESSENE.

After passing the gates, the road, formed of large blocks of stone, conducts to the city; these blocks are not polygonal, but oblong in their form.

The walls which remain at Messene are of regular blocks of stone, and at every 7 feet or more, there were cross walls at right angles to tie in the two faces, the thickness being too much for any other kind of bond. These walls, as restored, exhibit an arch over the principal entrance, for which there is no authority, although there can be little doubt but that such an arrangement was made over the wide entrances of the Greek cities.

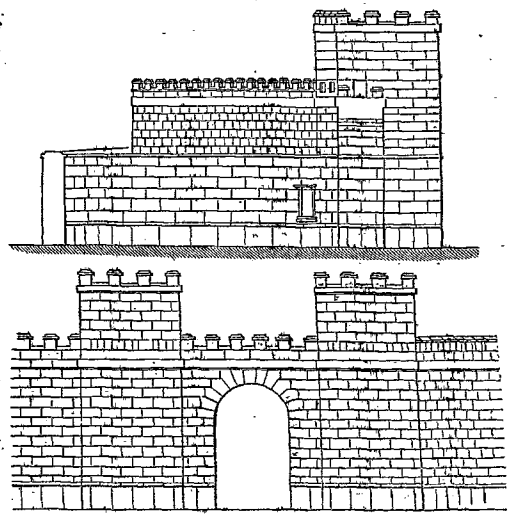


Fig. 78. MESSENE.

If we are right with regard to the time when the arch was used by the Egyptians, we may certainly suppose its adoption by a people who borrowed greatly from their inventions: we trace the embrasure and battlements in Egypt; the arrangement of the masonry, and securing the several blocks, indicates a similar origin. Time alone, and further research, must clear up this doubtful statement, and satisfy us upon a subject on which almost all writers differ.

The internal diameter of the circular tower is 17 feet 4 inches; it projects from the wall about 16 feet, the thickness of the masonry being a little less than 2 feet. The internal dimensions of the square tower are 17 feet 8 inches by 16 feet, and the openings on each side 3 feet 4 inches. The thickness of the walls 20 inches. The platform or walk along the battlements was in width 8 feet.

These towers were each two stories in height, probably entered by wooden ladders, as there are no remains of stone staircases. Square openings for the purpose of assailing those employed in the attack, were secured by internal metal bars. The lower tier of windows was splayed, that the archers might have a greater range for their aim. Such remains of military architecture among the Greeks, at once show us that the practice at this period was the same throughout all the countries which bordered the Mediterranean Sea. Pausanias describes similar fortifications; those by Homer differ but little from the examples here given.

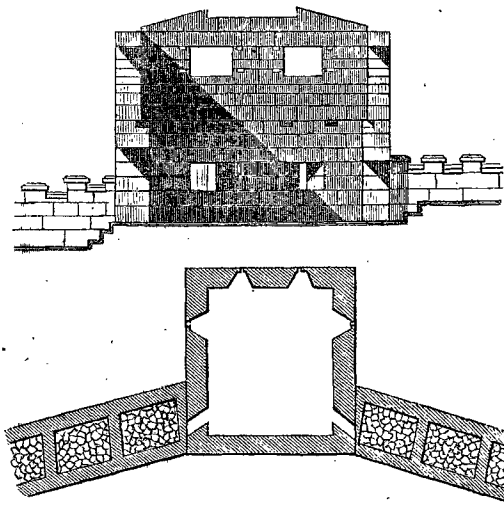
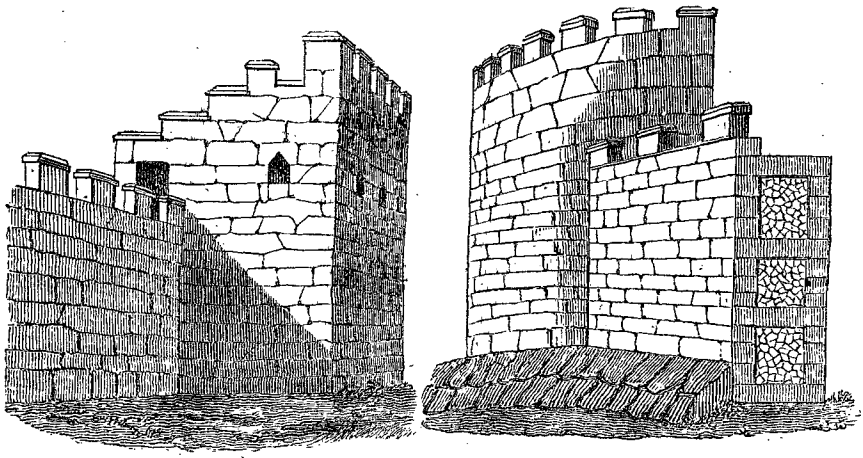


Fig. 79. MESSENE.



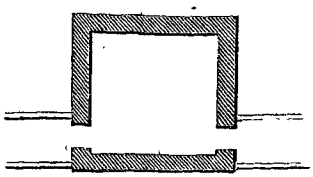


Fig. 80. MESSENE.

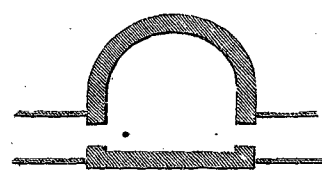


Fig. 81. MESSENE.

The battlements have been added from specimens met with in other parts of Greece, and the section of the wall shows the filling in between the two faces, also the method adopted to tie the whole together. Some of the apertures, or small windows, are finished

with triangular heads, cut out of the single stone which serves as the lintel. The towers were only raised a story above the ordinary level of the walls.

Argos had a similar tower, 20 feet 3 inches by 17 feet 7 inches in the clear, with walls about 3 feet 4 inches thick around it, supposed to have been the part of a Pharos, that served to alarm the inhabitants of the country around Tegea and Mantinea. The external walls were made to batter considerably, and if carried up would have assumed a funnel-like appearance, well suited for the purpose of a beacon.

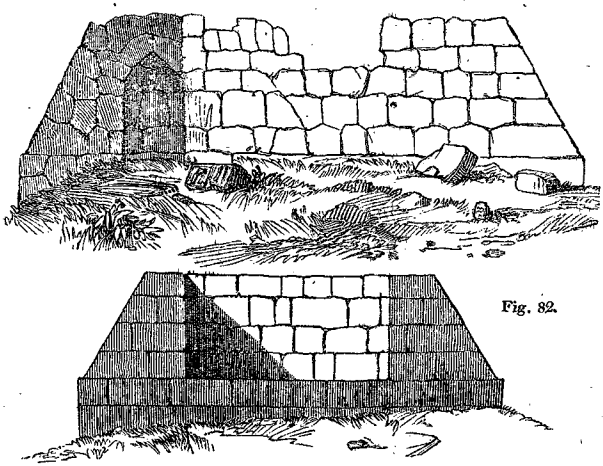


Fig. 82.

Many writers describe the manner in which these towers were set out, what should be their diameter, distance apart, and height, as well as the method of their construction; and that pieces of oak timber, four cubits in length, were introduced in the middle of the wall, to facilitate a repair in case a breach was made.

The walls of Athens were restored after the invasion of Philip, son of Demetrius, in great haste, when many public buildings were destroyed, and the materials used for the purpose: we see on the north side of the acropolis such a wall, where columns, triglyphs, metopes, and cornices are used, without order. The long wall of the Piræus, which has been already mentioned, was not commenced, according to Thucydides, lib. ii. cap. 75., until those around the city were completed; but it was set out near the Piræus of such a width that two carts loaded could conveniently pass. The length of the Phalerian wall to that part of the city where it joined was 35 furlongs; that part between the long walls and the Phalerian, 35 furlongs; and the length of the long walls down to the Piræus was 40 furlongs; and the whole compass of the Piræus, together with the Munychia, 60 furlongs.

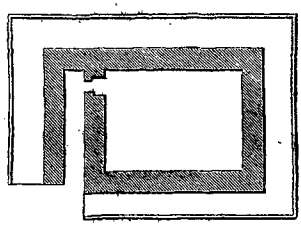


Fig. 82. TOWER AT ARGOS.

The engineer's skill was called forth by the early inhabitants of Greece, in the erection of the walls which surrounded their cities, and in the design and construction of the machines placed upon them for their defence. The artifice displayed in protecting or defending a long line of wall so fortified, was often matched by the besiegers, and we find improvement continually made, both in maintaining and taking a city, by the careful attention of those upon whom these duties devolved. The architect, well skilled in the arts of design, would be the best qualified to erect a stone barrier, either against a flood, or an armed body of men, as well as for raising heavy weights, and transporting them to any required distance; in the early age of society, he would be the most efficient director for all that now devolves upon the military and civil engineer. And as we learn from the ancient historians, that the architect had entrusted to him, not only the defences of the towns and cities, but also their arrangement, drainage, and general superintendence, we may infer that there existed no distinction between him and the engineer.

But the most important knowledge to him employed in the defence of a city or providing for its health and salubrity, would be a thorough acquaintance with the sciences, without which no great work could be devised or undertaken. Vitruvius, who had the care of all the engines of war entrusted to him by Augustus, tells us frequently in his writings, that those selected as engineers deeply studied the opinions of Pythagoras, Empedocles, Epicharmus, and other philosophers: Metagenes, Ctesiphon, Evangelus, Pæonius, Pephasmenos, Cetras, Polydus, Diades, Chœreas, Agetor, Diognetus, Tryphio, and many other eminent names, might be cited among the Greeks, who were practically acquainted with the use of machinery, and its applications, to the destruction of towns and cities, when called upon by the great generals of the age to exert their ingenuity.

The construction and demolition of their walls needed the aid of machinery, and among the Greeks a knowledge of all its proportions was thoroughly understood. The battering-ram, the balistæ, the catapultæ, the crane, the tortoise for filling up ditches and other purposes, and the several machines described for defence, show a thorough acquaintance with the properties of the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw; and Euclid's Elements, collected about 280 years before Christ, for the instruction of the pupils assembled at Alexandria, attest their advance in geometry.

The walls which remain in part at Platea more distinctly show the arrangement of the towers, battlements, and galleries between them. In some of the towers are staircases, and the whole is constructed of large stones.

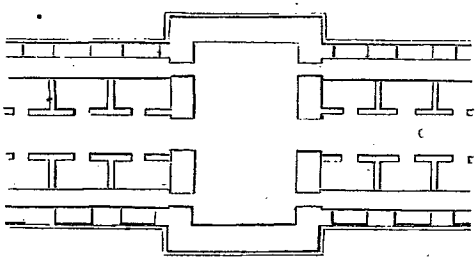


Fig. 83.

The double walls of the Peloponnesus, also described by Thucydides, were formed in portions of a double circle, one towards Platea, and the other towards Athens. They were distant from each other about 16 feet, and the space so obtained was divided into rooms by cross walls, which tied and united the whole together. At every tenth battlement was a tower, extending through both walls, and having its passage through the middle over the rooms, to which, during inclement weather, the guards might retire, and keep watch through the loop-holes contrived for the purpose. (Lib. iii. cap. 21.)

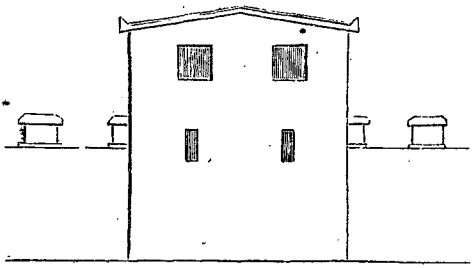


Fig. 84. PLATEA.

Amidst the discoveries in Lycia, made by Charles Fellowes, Esq. a few years ago, and published by that indefatigable traveller, were several gates of peculiar construction. That at Penara is Cyclopean, and formed of massive upright stones, with another laid over as a lintel, now broken. (See *fig.* 85.) There is also one which forms the entrance to a tomb having a pointed arch surmounted by the horns of a bull. (See *fig.* 86.)

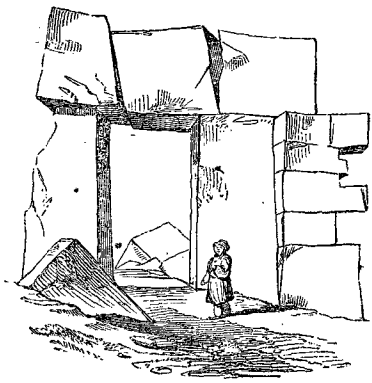


Fig. 85. PENARA.

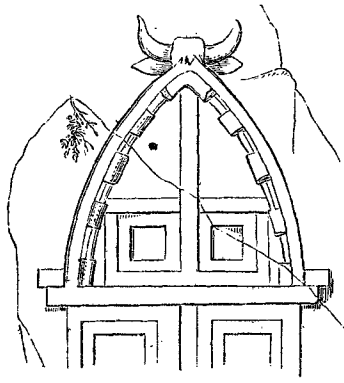


Fig. 86. PENARA.

There are great varieties of form given to the ancient portals, and it is curious to trace the changes from the rude Cyclopean method of discharging a weight over an opening, by the gradual projection of the stones meeting in the middle, to the formation of an equilateral triangle, as used by the Egyptians at a very early time, two stones, like the chord of two arcs, being placed one against the other. The approach to the regular portal is made at the gate of Penara, and this is rendered beautiful by the improvements added in that at Sidyma,

where a simple cornice with lion's heads protects the massive stones which form the square portal. (See *fig.* 87.)

In a tomb at Telmessus in later times we find the bold semicircular arch containing within the square portal formed of regular voussoirs, and set out with a thorough knowledge of its construction. This is thought to be of Roman work. (See *fig.* 88.)

The walls of Etruscan cities exhibit a more perfect construction; the Tyrrhenians in the

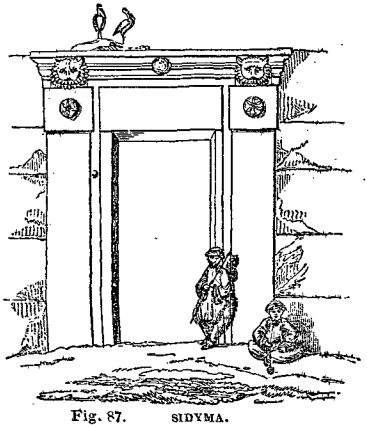


Fig. 87. SIDYMA.

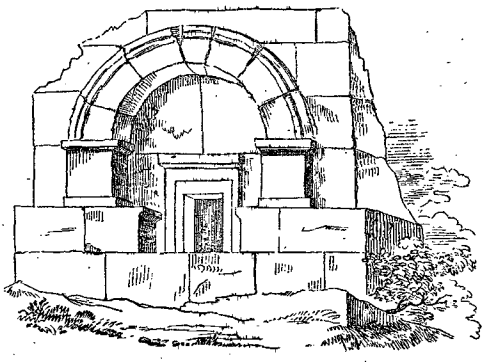
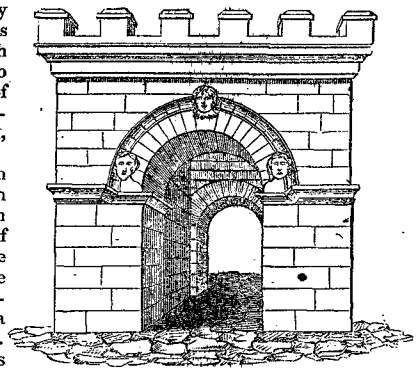


Fig. 88. TELMESSUS.

walls of Volterra, Cortena, Populunia, Roselle, Fiesole, Cosa, Luna, throughout Latium, and even at Pompeii, followed the manner adopted by the Pelasgi or Cyclops in Greece, though in the later example there is a nearer approach to regular masonry.

The blocks at Volterra are laid in nearly horizontal courses; and those at Cosa resemble the construction at Mycenæ. At Roselle, on the Ombrone, are vast ruins scattered over a hill, and the walls are nearly a mile and three quarters in circumference, constructed of a coarse limestone, or large masses of travertine, the outer face of which is perfectly level throughout. Some of these blocks are 15 feet in length, and their thickness is so great, that only two of these stones side by side are required for the entire thickness of the wall.

Cosa, near Orbitello, has its walls nearly entire, and those at Luna, an ancient maritime establishment of the Etruscans, were built in this manner. of pure marble, taken from the neighbouring quarries of Carrara. Many of these walls have their horizontal courses laid nearly parallel, whilst the joints which should be perpendicular are inclined; so that the stones are cut more in the form of a trapezium or rhomboid, their ends, in particular situations where strength is required, are dovetailed one within the other.



At Circei remains a rude entrance, which has a Cyclopean character, built up with stones without cement; and it would seem that among the Etruscans the progress of improvement kept pace with the Greeks: we have entrances to their towns, exhibiting the same style of construction, and in some instances vastly superior. That at Volterra has a semicircular arch, adorned with heads. (*Fig.* 89.) Another at Tusculum has its square-headed opening now inclosed within a regular pointed arch, which seems to have been constructed at the same time as the walls themselves, known to be of very great antiquity. Among the Etruscan remains this peculiar form of the arch is frequently found, but in the present example all the stones radiate to their respective centres, and leave no doubt as to the principle being thoroughly known; indeed, it is nothing

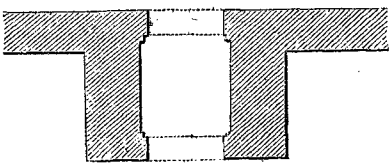


Fig. 89. VOLTERRA.

more than the result of taking out the middle voussoirs and bringing the other portions of the arch nearer together, or, in other words, narrowing the original opening, making use of the same stones which served for a semicircular arch. Such an accidental adaptation may have been the cause of the pointed arch. In some of the cities of Etruria, particularly at Tusculum, are the remains of arches similarly constructed with that in *fig.* 90., but its date remains uncertain. This example has been adduced as an early specimen of the use of the pointed arch; it forms a portion of a subterraean course or conduit, through which the water was brought to the reservoir distributed to the lower portion of the city. The aperture, which formed the entrance to the emissary, is narrower at top than at bottom, and covered by a single stone lintel. Had we any authority for affixing a date, we should no longer be in doubt as to the origin of the pointed arch; but we have not evidence by which we can trace its introduction, or decide whether it is not the work of a much later epoch than that assigned to it.

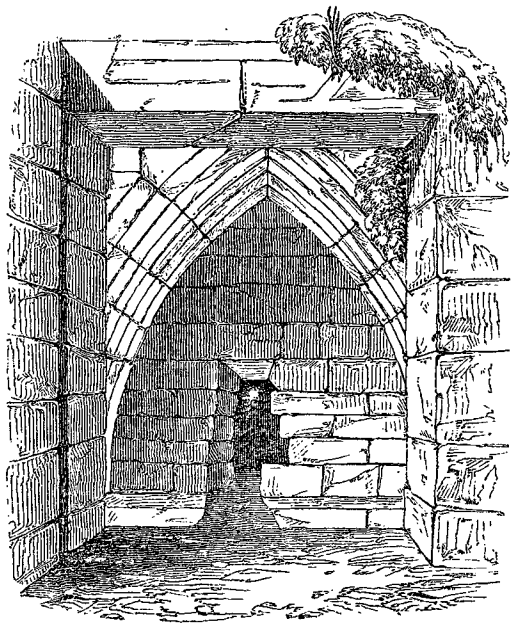


Fig. 90. TUSCULUM.

The great resemblance the walls of the Etruscan cities bear to those of Greece indicates a common origin, or that they were the work of the same tribes, though scattered on various shores. Tarchon, the son of Tyrrhenus, a Lydian prince, was supposed by Cato to be their great leader to the plains of Italy; and if his followers were drawn from the shores of Asia Minor, we have no difficulty in accounting for the remains, appertaining to the arts, dug up at Naples, Capua, Verona, and Padua, resembling those discovered throughout Greece.

Etruria, bounded by the Tiber on the east, by the Maira on the west, by the Tyrrhenian sea on the south, and by the Appenines on the north, according to Polybius and Herodotus, had its inhabitants from the Asiatic coast; their language nearly approached the Hebrew or Phœnician, and their alphabetic characters were the earliest used in Italy. Of the inscriptions remaining, there is enough to indicate, particularly in the latter period of their institutions, a Greek connection. Etruscan artists were always held in high repute, and in the early history of Rome, we find them selected to construct what was necessary for the embellishment of the city. If the Pelasgi or Phœnicians were the civilisers of the shores of the Mediterranean, we must follow them, to account for the similarity of manners and customs. About 2080 years before Christ, they founded in Egypt the dynasty of the Hucsas, which Sesostris drove out about 500 years afterwards. Greece received its first colony under Inachus, 1986 before Christ, which was followed by others under Danaus, Cecrops, Cadmus, Deucalion, Pelops, and various Phœnician or Pelasgic chiefs. In the course of time, the settlers driven out by Deucalion from Thessaly, who had settled at Epirus, retired or went over to Italy, carrying all that was valuable, and established themselves first on the coast. This seems probable, and enables us to account for the similarity of their habitations and arrangements as well as in their engineering works.

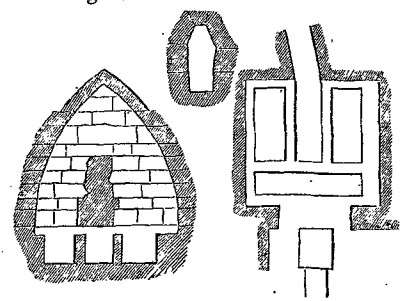


Fig. 91. TUSCULUM.

Treasuries were generally added to the Greek cities at a very early period. According

to Pausanias, Minyas, who governed in Bœotia, erected the first at Orchomenos, and the wealth contained in that at Delphos is mentioned by Homer, where Achilles rejects the offer of Agamemnon.

The treasury of Atreus at Mycenæ, and another at Hyrieus, is described by Pausanias. When the writer measured the first-mentioned building in 1818, there was no portion of the doorway which inclosed its interior, although much might be traced to indicate its position and thickness. It was supposed to be of bronze, and with this metal the interior, is said to have been cased. By some the building in question is considered as a tomb; it is of a conical shape, about 50 feet in diameter. The courses of stone are all laid horizontally, and, by gradually projecting one over the other, assume the character of an arch, or rather that of a cone (*fig.* 93.), the form adopted by Sir Christopher Wren in the brick construction which carries the timber dome at St. Paul's. This method of gathering over concentric rings has been practised by people of all nations; we find it not only in Greece, but in Italy, where as late as the thirteenth and fourteenth centuries it was made use of at Pisa, in the baptistery. Around the Treasury at Mycenæ the earth is bedded up to the stones, and the entrance was by a passage closed by ornamental jambs, with a door or gate. Within the first circular chamber was a second, entered by a square door, which had a large stone for its lintel, the weight above being discharged by a gradual gathering over of the courses. It is nearly 50 feet in diameter and in height; two stones cover the entrance passage, one of which is 27 feet long, 16 feet broad, and 4 feet thick.

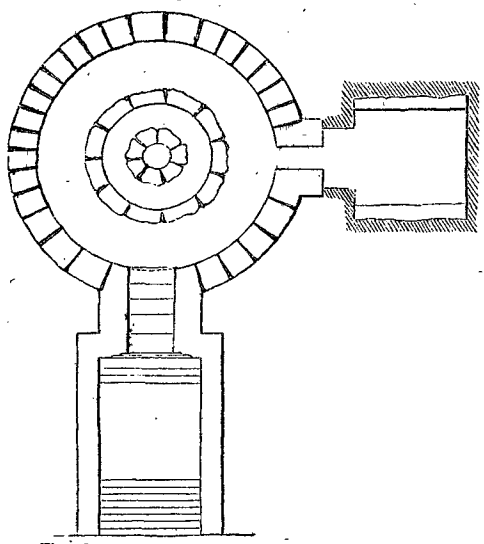


Fig. 92. MYCENÆ.

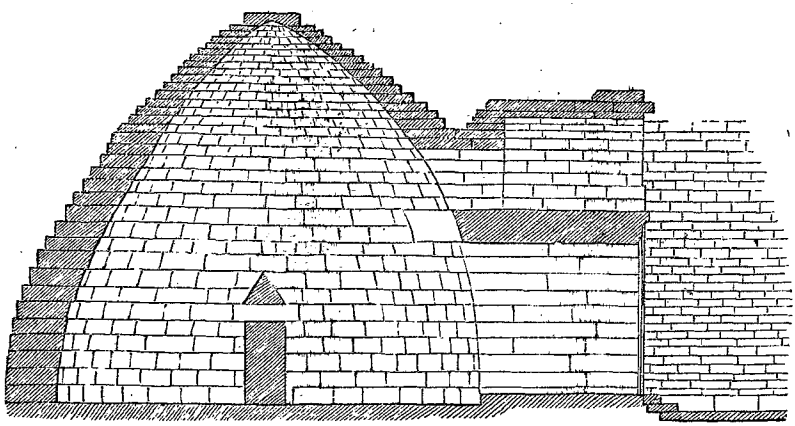


Fig. 93. MYCENÆ.

The Greeks, the inventors of many of the arts of construction, have left us, in their tombs, forms serviceable to the civil engineer, and which tell us also of the gradual progress made in architecture.

In Mr. Fellowes's volume, the method adopted by the Lycians of cutting their tombs out of the solid rock is admirably given; in some examples we have imitations of timber

construction, in which the covering is carved to represent rafters, &c. In another, at Myra, is a window, admirable for its lightness and delicate proportions, as is the other variety here selected. The first principles of architecture are indicated. All the ties to hold in the upright timbers, which bound the figure, are expressed as they would exist in a timber construction. The rafters have the characters of round timbers, laid side by side, or as made out of the tops of the cedar or fir tree. There is in this picturesque

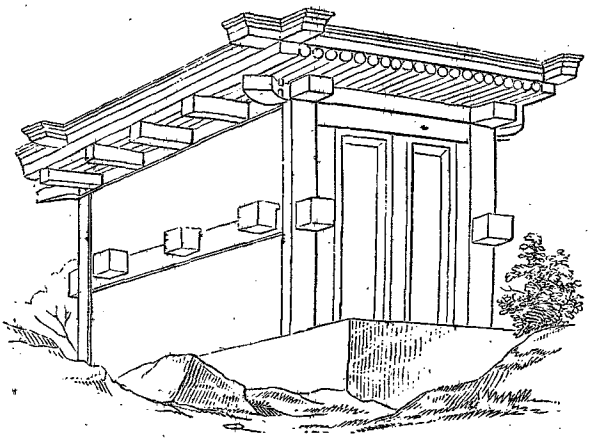


Fig. 94. LYCIA.

fragment a beautiful proportion reigning throughout; it shows the great taste and happy execution of the masons employed in designing and working these chambers for the reception of the dead. (See *fig.* 94.) The same may be found executed in the walls of the Sicilian towns, particularly at Agrigentum, though by no means of so perfect a design. That architecture had its origin among a people who used timber for their construction has been generally admitted, and, indeed, most of the parts of the Greek orders seem to have their proportions from the scantlings of wood.

In the "Antichità della Sicilia per Dominico lo Faso Pietrasanta Duca di Serradifalco." the engineer and architect will find ample historical and practical information to satisfy him, upon the embellishment and defence of the early Greek cities, throughout that elegant and erudite work, we have evidence that every stone has been turned and examined that could lead to an understanding of its use; the great taste evinced in the arrangement, the correctness of the maps and plans of the several harbours on the coast, render it highly important that all who take an interest in the study of this subject should have it in their possession; it contains an ample account of the labours and studies of the civil engineer, throughout Sicily, during a period the most interesting.

Wherever a staircase, conducting up a slope to one of these sepulchres, required a parapet to protect the sides, the stones were cut out of the solid, and formed the last of each course; by this arrangement considerable strength was obtained, and, by the manner in which they were placed, cramps were dispensed with. Stones so united or tied together, were well adapted for a staircase between two walls. (See *fig.* 95.) The science belonging to architecture was derived from the Greeks, and differs materially from the art itself: in the former, theory and practice constitute the essence; in the latter, the imagination is necessary. One, then, is the system of knowledge reduced to practice and unerring rules, which, on all occasions, must guide the engineer and architect in the carrying out of his designs; such a science is deducible from truths, and their relation to one another. After the rude artificer had discovered the essential supports requisite for the construction of his cabin or residence, he would then endeavour to give it a form pleasing to the eye, or an expression denoting its purpose. Before the main supports of an edifice assumed the character of columns, or the timber which rested on them that of the architrave, a more simple and rude manner of framing was expressed. The square upright, mortised through to receive the tenons of the horizontal timbers, is the most simple holding or tieing together that can be well imagined; to execute which, few tools, or not more than those said to have been invented by Dedalus, were required. Practice soon taught the strength of the various qualities of timber, and the necessity of cutting off from the tree all that was sappy or likely to be affected by the weather: hence squared pilasters, or antæ, were probably first preferred to round trees, which more resembled a column.

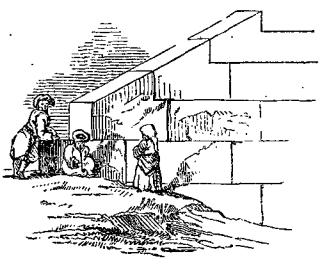


Fig. 95.

Timber exposed would require care, whilst that which formed the rafters, and was protected by the roof or covering, might be allowed to retain its original rotundity, as the exterior could not be affected by the weather. In these few examples we fancy we can trace the germ of all that was afterwards rendered beautiful by art, and in them the rudiments of that fine fancy which guided the Greeks to the excellence we admire in all their designs.

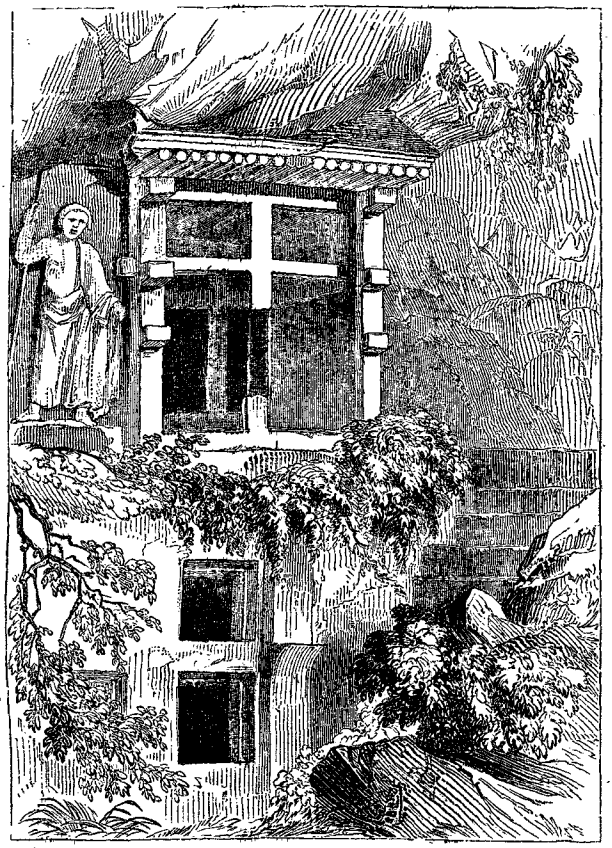


Fig. 96. MYRA.

It was Cadmus, according to Herodotus, who introduced into Greece an entire change in architecture; the Phœnicians that accompanied him had among them a body of Gephyrians, who wherever they went carried a knowledge of the sciences and letters; the poet Lucan tells us the Phœnicians were first acquainted with the mystery of letters, and could write down or figure the thoughts of the mind; from them the Egyptians acquired their knowledge. To these Gephyrians, who came from Eretria, a city of Eubœa, has been attributed all the changes which architecture underwent in Greece — that they commenced buildings of stone in imitation of the wood huts formerly used. Cadmus, who lived about 1500 years before Christ, introduced the Egyptian and Phœnician forms of worship to the Greeks; and the system of working and building in stone, as practised by the people of that nation, may be attributed to the Gephyrians at the same epoch. It has been assumed that the various elements of Greek architecture were drawn from the buildings constructed by the inhabitants before the arrival of these scientific colonists, who were struck with the features presented by the original hut, and engrafted in their designs all that was so pleasing and agreeable to the eye. Our great author, Vitruvius, tells us distinctly, that the Doric order had its origin from wooden buildings; and if so, to timber constructions we must refer for the invention and forms of all we find executed in stone; and the mason called upon to shape the rock or give its face an architectural arrangement may have had a wooden model for his imitation, which may also account for the resemblance to timber framing in the example before us. The principles of construction ought, however, always to be in accordance with the material, the property of stone differing from that of wood; the latter may be applied to tie and hold a building together, by the toughness and strength of its longitudinal fibres, whilst stone, however strong or tough, so used, would readily be torn asunder.

Among the ornamental works of the Greeks we have frequently animals, plants, and flowers imitated in marble, but always with so much delicacy that the material loses its character, and seems to become identified with its subject.

The civil engineer, when called upon to work out masses of rock, has opportunities afforded him to imitate these original conceptions, and produce an effect upon stone which almost indicates the employment of another material; not that the eye should be wantonly deceived at any time.

In these sepulchral abodes the character aimed at is that of an habitation; the hewer of stone here has, perhaps, impressed upon his material the resemblance of the dwelling once tenanted by the occupier of the tomb; from so humble an effort we have handed down, in an imperishable material, the style of construction used by the Lycians at a very early period, and so universally adopted by the nations spread along the shores of the Mediterranean. We must not inquire into the fitness of the material employed to give expression, but allow praise to the design, on account of its conveying to us a resemblance of what was most dear to the deceased when living; here we have an abode provided for the dead, far more cheerful in its character than the pyramid or conical mound of earth.

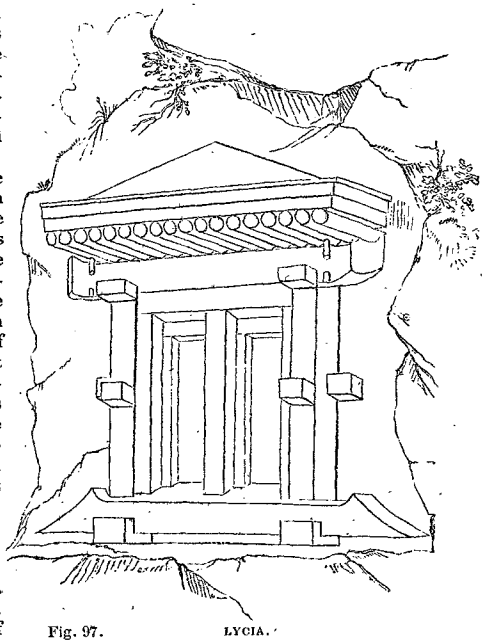


Fig. 97. LYCIA.

That the inhabitants of Lycia retain the forms of their earlier constructed buildings, we have evidence in the examples before us, where the several cottages and storehouses resemble temples. (See *fig.* 98.) Others built of mud and straw are covered with timbers, on which is spread a layer of stone, above which is laid a tenacious earth, kept pressed and rolled down till it becomes perfectly water-

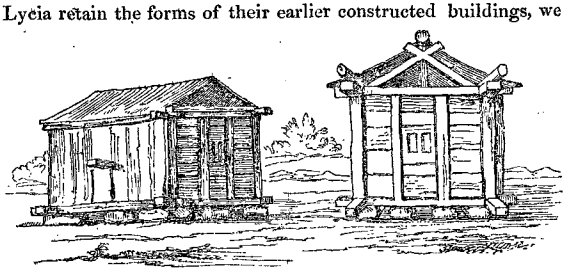


Fig. 98. LYCIA.

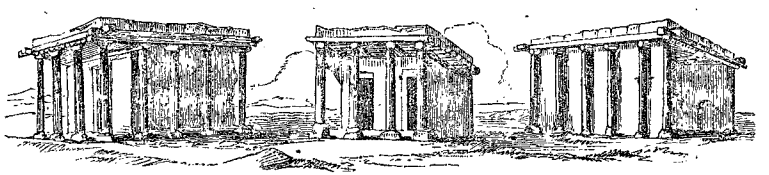


Fig. 99.

tight. Plants spring up on this artificial terrace, which may have suggested the various forms which the Greek architects gave to the covering of their buildings. (See *fig.* 99.)

The maritime works of the Greeks are now only known to us by reading the accounts handed down by their historians. Most of their harbours are destroyed, and their constructions in stone overthrown, yet, by a careful examination of the remains, much might yet be discovered: the smallness of their vessels did not require very deep water for their security; shallow seas or inlets from the main were usualy preferred by their mariners, around which they constructed arsenals, magazines for stores, lighthouses, and other buildings necessary for commerce and for protection.

CHAP. IV.

ROMAN ENGINEERING.

ITALY, whose history is involved in obscurity, at an early period was divided into the states of Liguria, Gallia Cispadana, Gallia Transpadana, Etruria, Umbria, Sabinum, Latium, Picenum, the country of the Vestini, Marrucini, Peligni, Marsi, Frentani, Samnites, Herpini, Campania, Picentini, Magna Græcia, Apulia, and others.

The Etrurians were among the first to distinguish themselves by their victories over the neighbouring tribes, and by their attention to commerce and the arts of peace, which they learnt from the Phœnicians. The islands of Corsica, Sardinia, and Elba afforded them materials for ship-building, and metals for the fabrication of all sorts of tools. Military architecture by the Tuscans was greatly improved, and the ruins of their towns on or near the coasts at Luna, Pisa, Leghorn, Civita Vecchia, and many others, prove them to have been also a maritime people. To them succeeded the Roman Empire, which could boast of dominion over 1197 cities in Italy, 360 in Spain, 300 in Africa, 500 in Asia, 1200 in Gaul, and several in Britain. Roads of the best construction were every where made to unite these cities; and the coasts which did not afford a natural protection to their ships were furnished with artificial ports. The power which grew up in this vast empire diffused its advantages over the whole world. Agriculture, which was made a science and lauded by the poets, introduced plants of every kind to soils of distant lands where they were likely to flourish. The sciences followed in the train of their conquests, and engineers of talent were attached to their armies on their march, and established in every great city of their empire. Emperors distinguished themselves in the prosecution of great and important engineering works, and all who became enriched by the spoils of their enemies expended some portion for the benefit of their country: thus the blessings and luxuries of life became universally distributed over the whole of Europe. By the Romans civilisation was spread far and wide; they made use of the talent which every where sprung up, and by their encouragement naturalised it and made it their own.

Architecture and civil engineering are both treated at great length by Vitruvius, and we cannot do better than follow the order, as well as description, of that able writer, who, it must be remembered, is our only early guide, without whose labours we should need an explanation of some of the simple terms made use of in the descriptions left us by other authors. The inventions of many Greeks would not have been known to us if he had not handed them down. He lived and wrote when Rome was at its greatest pitch of glory; and we have no reason to doubt that the rules he gives for construction were different from what were in those days most approved.

The Romans founded towns wherever their arms were victorious, and paid great attention to the selection of their site, that it should not be under the influence of noxious or pestilential vapours, but well provided with all the conveniences necessary to sustain life and health.

Vitruvius informs us the neighbourhood of marshes was avoided, and that the aspect for towns should not be directly south or west when founded on the sea-shore, otherwise the scorching heat of the sun would be inconvenient. By the Greeks air was called Pallas, and by Homer Glaucopis, which indicates a quality clear and transparent; but the ancients were not acquainted with its properties, or the manner it which it administered to the nourishment or support of life; the lightest and clearest they considered the healthiest, and, by inhaling pure air, that their imaginations were improved. On this account the Athenians were considered more intelligent than the Thebans, who were living in a humid atmosphere.

The Romans, in setting out a camp, commenced by sacrificing animals, the livers of which they carefully examined: if they found any disease, they subjected others to a like test; if the greater number proved to be healthy, it was then considered that the soil and water were fit for the use of man, and the encampment was completed. In the same manner, previous to the foundation of a city, every necessary inquiry was made upon all these subjects, and also upon the best system by which the drainage could be effected. If circumstances required it to be established in a marshy situation, near the sea-coast, a northern, north-eastern, or eastern aspect was preferred, care being taken that none of its foundations should be so low as to render it incapable of being thoroughly and effectually drained. The sewers were laid out so as to discharge all superfluous waters into the sea; the lands

round the city were thoroughly drained, and by this means all the cities in Cisalpine Gaul, Ravenna, Aquileia, and others, were rendered healthy. It is recorded that the inhabitants of Salopia in Apulia, being continually out of health, applied to Marcus Hostilius for permission to remove their town to a more healthy spot, when a site near the sea was purchased by consent of the senate and Roman people, and the new work commenced, each citizen having a portion of ground allotted him at a moderate price. A communication was afterwards made between the lake and the sea, by which the former was converted into an excellent harbour for shipping. The Salopians thus acquired a healthy situation four miles from their former city, and had all the advantages they desired. The Romans always thought of the best means for providing the inhabitants with the necessaries of life, and for holding communication with other portions of the empire. They would not have followed that advice which the architect gave to Alexander, to cut Mount Athos into the figure of a man holding a city in one hand, and collecting the waters of the mountain in the other, if the country around had been barren or unprofitable. A region more accessible both by land and water would have been preferred by the Roman engineers, where water was of a quality not injurious to health, and sufficiently abundant for the wants and luxuries of the citizens. They carefully examined into the health of the people that occupied the region where a new city was to be founded, they observed the effects on the buildings which existed, and the trees, whether they indicated, by their bending in one direction, any prevalent or continued high winds. They also observed the surfaces of the natural stones and those used in the dwellings of the natives, whether any decomposition had taken place, or the atmosphere had acted injuriously upon them.

After the site was determined upon, wells were sunk to try the nature of the soil; if fit to bear the weight of the constructions intended to be put upon it, they commenced their foundations for the outer walls, which were always based upon a solid stratum; the workmanship as well as the materials employed for this purpose were the best that could be obtained on the spot or in the immediate neighbourhood,—square stones, flint or rubble, burnt or unburnt bricks, bonded together with timber, as that of the olive, or some other equally imperishable wood. The works were conducted by the military or civil engineers, and every means adopted that could render them proof against the attack of an enemy. Vitruvius recommends that the plan of the city should be polygonal, because the angles of a square or parallelogram are defended with more difficulty. The towers should, he observes, be also round or polygonal, the square towers being more easily injured at the quoins by the battering-ram. When the wall which surrounded the city was constructed on the side of a hill, buttresses were added, distant from each other as much as the height of the wall, or, if requisite, nearer together. They were gathered in gradually, to give additional strength. Every precaution was taken against assault by an enemy; angles jutting out were avoided, as they were considered to assist the enemy when making an assault, and to be injurious to the inhabitants in the defence, and that they were weak against the military engines brought to act upon them. Whatever form was adopted for the walls, they were made of such thickness as would permit two armed men to pass each other behind the parapet, of a sufficient height to prevent the scaling ladder from being applied to them, and built so firmly as to resist the battering-ram.

Varieties of military engines were employed to demolish or break down the walls, and some to undermine the foundations; as a security against these, a deep ditch usually surrounded the outside of the wall. These ditches were often without water, and made sufficiently wide and steep to defy the approaches of the moveable towers, or tortoise, brought to act against the fortifications. The city had two walls, if it was of much importance, a space being left about 20 feet in width, or more, between them, which space was filled with the earth taken out of the ditch, well rammed in: this inner wall was provided with flights of steps in every convenient position, that it might be easily mounted from the side towards the city. When there was no ditch, the space between these two walls was left open, where the soldiers were ordinarily assembled. Cæsar informs us, that in Gaul most of the walls had beams of timber laid within them at regular distances, in a parallel direction, braced together and tied diagonally, the spaces being filled in with large stones, so that neither fire nor the battering-ram could injure them.

The towers which project from the outer walls, whether round or square, were usually carried up higher than the wall itself. And the inner wall of these towers, on the face towards the town, was left open, that, if an enemy got possession of them, he was not protected from the assaults of the inhabitants: they were often crossed by wooden platforms or bridges, which could be easily demolished, and thus the walk along the top of the wall, or behind the battlements, destroyed.

The walls and towers externally were finished by a bold projecting cornice, which received the battlements, and gave greater width at the top of the wall, as well as prevented the easy application of the scaling-ladder. Where the city was entered by the inhabitants on ordinary occasions, the gate was flanked by two towers, larger than the others, and more

strongly fortified. The floors were of timber, not fastened very securely together, so that they could be easily removed if necessary.

The city of Rome is of great antiquity: at a very early period it occupied only the Palatine hill, which being cut away at its slopes, a perpendicular face was given to it, strongly fortified by a stone wall built upon its edge. As the inhabitants increased, the original city became the citadel, and buildings were constructed around it. Roma was the name it bore at the time it was inhabited by the Pelasgi, the Tyrrhenians, or Sicelians. Around the ancient citadel Romulus added a space, which was inclosed by a wall, called the pomærium, signifying a suburb, or place admitted to the privileges of the city. Tacitus (Ann. xii. 24.) says it may be a matter of some curiosity to mark out the foundations of the city, and the boundaries assigned by Romulus. The first outline began at the ox market, or Forum Boarium, where is still to be seen the brazen statue of a bull, that animal being commonly employed at the plough. From that place a furrow was carried on of sufficient dimensions to include the great altar of Hercules. By boundary stones, fixed at proper distances, the circuit was continued along the foot of Mount Palatine to the altar of Consus, extending thence to the old Curiæ, next to the chapel of the Lares, and then to the Roman forum.

Another suburb afterwards was added with a wall of earth toward the Subura: this was on the Carinæ near S. Pietro in Vincoli. At the bottom of the ascent which led to it was the Porta Janualis mentioned in the Sabine wars.

The Agonian hill, inhabited by the Quirites, and called Quirinal, was a town at a very early period; this was next united with the Capitoline, on which was the citadel. Where these two hills joined at the foot stood the Forum Ulpium. The Palatine was separated from them by a marsh or swamp, the Quirinal being at one period occupied by the Sabines.

Roma and Quirium were separated by walls, and formed two distinct cities, at first each having its king and senate of an hundred men; these met together in the comitium situated between the Palatine and Capitoline hills.

After these two cities were united, the Temple of Janus was built, on the way leading from the Quirinal to the Palatine, with a door or gate facing each city; this temple was kept open in time of war, and shut during peace, the object being, in the one case, to afford succour to each other when harassed by an enemy, and, in the latter, to prevent the inhabitants of either from quarrelling, the result of too frequent an intercourse. The Via Sacra marks the limits of the two cities; this commenced at the top of the Velia, between the Quirinal and the Palatine, after making a turn, passed between the latter and the Capitoline, and, arriving at the temple of Vesta, it bent across the comitium towards the Palatine gate. This was the Sacred Way, and seems to have served the purpose of the inhabitants of both cities during their religious processions. The cities were afterwards united, and called *Populus Romanus et Quirites*.

The Capitoline, Quirinal, and Viminal, were first surrounded with walls and incorporated with Rome, and afterwards the other hills. In the age of Tiberius we find the city considerably increased, and divided into seven districts — the *Palatium*, *Velia*, *Cermalus*, *Cœlius*, *Fagutal*, *Oppius*, and *Cispius*, which had each its own festivals.

The Velia was the rising ground between the Palatine and the Carinæ, where is the temple of Peace and that of Venus and Rome.

Oppius and Cispius are the hills now called the Esquiline. Cermalus is the land at the foot of the Palatine, subject to be flooded from the Velabrum.

The Fagutal district was probably that plain which lay between the Palatine and the Cælian, the Septizonium and the Coliseum.

These several districts were not encompassed by a wall; and the Romans never reckoned more than seven hills, or as many regions.

On the side of the Via del Colosseo, Romulus's pomærium reached the rising ground that protected the Carinæ; beyond, in the valley, was the village of Subura. The Cispius and Cælian hills were fortified by a wall and ditch where the banks could not be cut down perpendicularly, and the Aventine being insulated was strongly protected. The low land between the Palatine and Cælian hills was full of springs; these were collected in a ditch cut from the edge of the Aventine to the Porta Capena, and the earth thrown up as a wall to protect it: this was done by the Quirites in the time of Ancus, who, Livy tells us, after the conquest of Politorium, a city of Latium, first numbered its inhabitants among the Roman citizens. At that time the Romans occupied the ground around the Palatine, the Sabines the Capitol, and the Albani the Cælian. The Aventine was allotted to the new citizens; and some time after, on the reduction of the Tellenæ and Ficana, a considerable addition was made to the inhabitants. Ancus afterwards admitted many thousands of the Latins as citizens, and allotted them ground near the temple of Murcia, and united the Aventine to the Palatine. The Janiculum was taken in at the same time, and joined to the city by a wall, and a wooden bridge, the first built over the Tiber.

Servius Tullius added the Quirinal and Viminal hills, and extended the limits of the Esquiliæ, where he established his own residence. He also surrounded the city with a rampart, trenches, and a wall. By this means, the pomœrium on each side of the wall was extended, which space it was the custom of the Etrurian augurs to consecrate. On the inside of the wall no buildings were admitted, the space being required for defence.

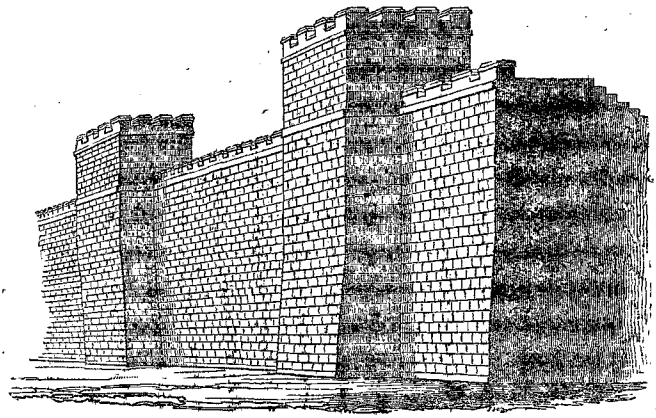


Fig. 100. WALL OF SERVIUS TULLIUS.

The wall built by Servius Tullius surrounded the entire city, the Colline and Esquiline region being connected by a mound 7 furlongs in length, formed with the earth thrown out of a ditch 30 feet in depth, and above 100 feet in breadth: here was raised a wall 50 feet wide, above 60 feet high, and, although chiefly built of puzzolana, faced, towards the moat or ditch, with hard stone, and defended with towers. The Colline gate was situated where the Quirinal was nearly flat, and from thence, up the acclivity of the hill, a similar wall was constructed.

The Viminal hill, so called from the osiers it produced, was then taken into the city, which, at this time, measured about 6 miles in circumference. The city of Rome remained in this state for centuries; but the ramparts which defended its citizens were not sufficient in the time of the Emperor Aurelian to satisfy them. Beyond the wall around the seven hills, numerous buildings which had been constructed in the suburbs were now inclosed; the city and its inhabitants covered the field of Mars, and also extended their dwellings for a considerable distance on the various roads which led from it. The new walls, built by this emperor, and finished by Probus, were in circuit about 21 miles, and comprised nearly the whole of the suburbs. Probus also built a stone wall from the Rhine to the

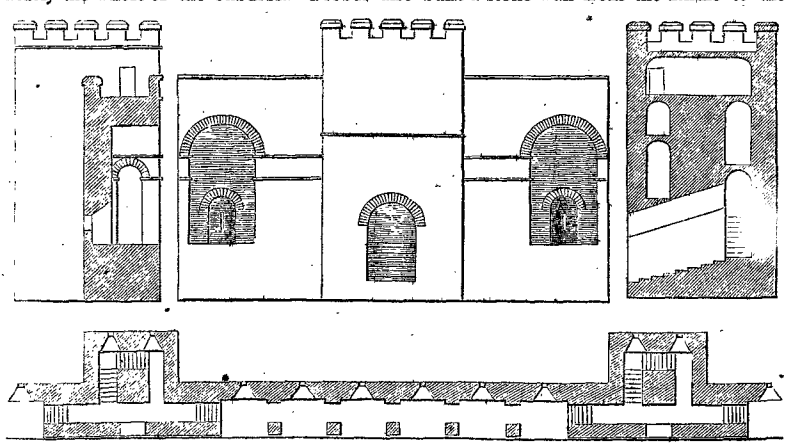


Fig. 101. AURELIAN'S WALL.

Danube, of a considerable height, and strengthened it by towers at regular distances: it passed from Newstadt and Ratisbon, over hills, valleys, and rivers, as far as Weimpfen on the Neckar, and terminated at the Rhine, after a winding course of 200 miles. This wall was overthrown by the Alemanni, and its scattered ruins may be seen in several places.

A portion of the wall which remains between the Porta S. Giovanni and the Amphitheatre Castrenses is constructed in the manner called *opera laterizia*, and is defended with square towers, having a base of squared stone of an earlier construction. On the inside the gallery is carried on a series of arches, and is arrived at by staircases in the towers; the total thickness of the wall is about 14 feet, and the width of the gallery about 4 feet. The towers are in width about 24 feet, and project 12 feet. (*fig.* 101.)

Rome was comprised within the circuit of the walls built by Servius Tullius, who also more strongly fortified the Capitol, by surrounding the edge of the rock with a stone wall, strengthened by square towers, placed at regular distances. Part of this may be seen on the western side of the Capitoline hill, but the greater portion was destroyed in the time of the Caffarelli, when its thickness was found to be upwards of 20 feet, built of very large squared blocks of pepperino.

Near the ruins of the baths of Diocletian, and between the Viminal and Esquiline hills, are the remains of the celebrated *Agger* of Servius Tullius: it continues for upwards of 100 feet in length, and to a height of 30 feet. In the middle was placed the Viminal gate: the Agger was formed with the earth taken out of the trench in front of the wall.

The wall here was formed of squared stone laid in regular courses, and strengthened by square towers, (Dionysio, lib. ix. Strabo, lib. v.): it has been restored and repaired at various times: the city at present is entered by sixteen gates. Pliny tells us that the wall of Romulus had only three, and that of Servius Tullius seven. In the part which Aurelian added on the other side of the river were also three. In the time of Pliny, in the reign of Vespasian, there were twenty-four gates; and when P. Victor wrote during the reign of Valentinian, thirty-seven. In the year 1749, the whole circuit of the walls was

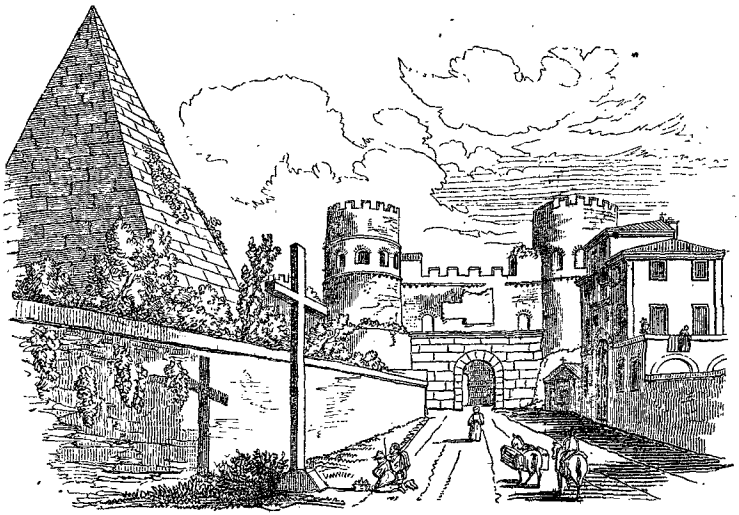


Fig. 102. GATE OF ST. PAUL.

repaired, and, although built at various times, are to the antiquary highly interesting. In the present gate leading to St. Paul, out of the walls, the various changes that have been made may be traced: on the left is the Pyramid of Caius Cestius. (See *fig.* 102.) A portion between the Porta del Popolo and Pinciana is built on arches, with deep recesses, and sometimes with two rows of arches, one above the other. The masonry is composed of opus reticulatum, which was much used in the time of Vitruvius, who considered it not very durable.

The Muro Torto remains, although much out of the perpendicular: Procopius, who wrote in the sixth century, informs us that near the Pincian gate he saw this rent wall, which seemed to have been long in that state; and that when Belisarius wished to pull it down, he was prevented by the Romans from doing so. Near the Porta Maggiore is

a part of Aurelian's wall, having open arches at the top, which served as an aqueduct; this portion is of greater antiquity, probably of the time of Claudius.

In the time of Pope Leo IV. the Vatican was walled in, and six gates admitted to its enclosure. In the year 1143, Urban VIII. built another wall on the outside of the Leonine city.

Circeium, or *Circeia* (*fig.* 103.), not far from Anxur, is situated on the low land bordering on the sea. The promontory upon which it stands, in the days of the Argonauts, is said to have been occupied by the Turrheni. The Volscians are reported to have taken possession of it, in whose hands it remained until Tarquinius Superbus conquered it, when he sent his son with a Turrhenian colony to settle there. The Volsci again recovered it, and drove out the Romans, in the time of Coriolanus, and it afterwards became a Roman municipium.

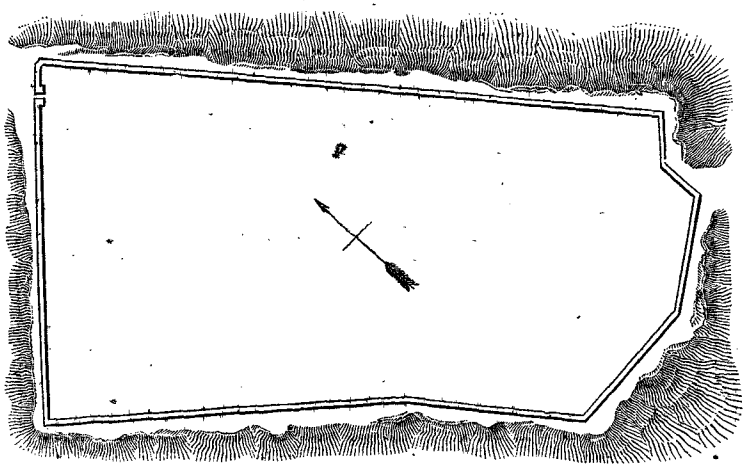


Fig. 103. CIRCEIUM.

An area of about 600 feet by 300 is enclosed by a wall of polygonal blocks, laid after the manner of the cyclopean, and the single gate which enters it at the north-east angle is curious for the size and disposition of the stones which discharge the weight over the opening, one of which, nearly 8 feet in length, lies like a lintel in a horizontal position upon two others which project over the perpendicular line of the jamb, to relieve its bearing. (See *fig.* 104.)

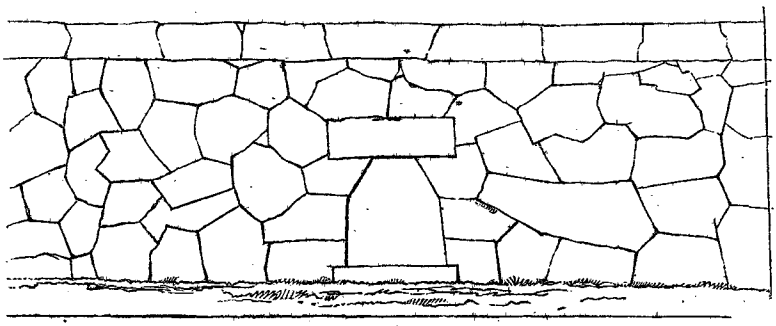


Fig. 104. CIRCEIUM.

Spello in Umbria affords us an excellent example of a gate flanked by polygonal towers: there are three entrances decorated with simple pilasters, and a gallery above. The staircases within the towers are circular, and the tops have the first indications of machicolations. The battlements remain, crowning portions of the walls which once surrounded this ancient city, and in them we recognise the Greek or Etruscan origin, which was not departed from during the middle ages. (See *fig.* 105.)

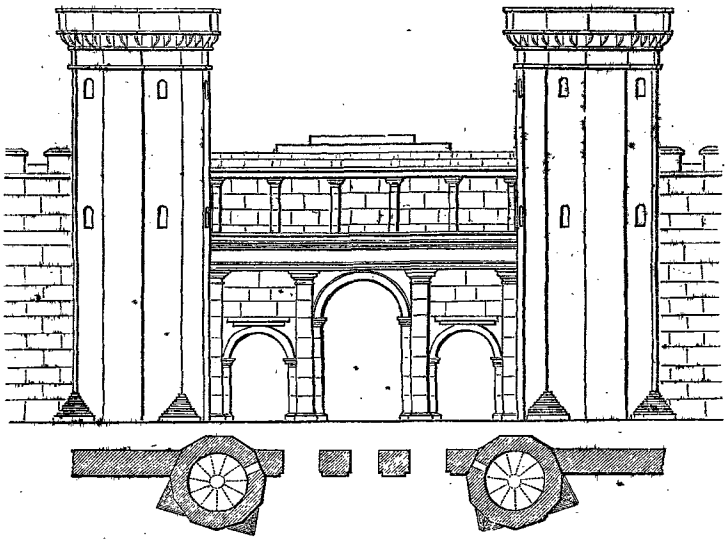


Fig. 105. GATE OF SPELLO.

City and Gates of Augusta Prætoria, in the valley of Aosta, between the Alps Graiæ and Penninæ, or the Great and Little St. Bernard. This city was founded after the defeat of the Salissi, who inhabited Cisalpine Gaul, and who were continually at war with the Romans. In the days of Augustus the gate was built: it is an admirable specimen of the entrance to a Roman city. The walls are set out at right angles. The two longer

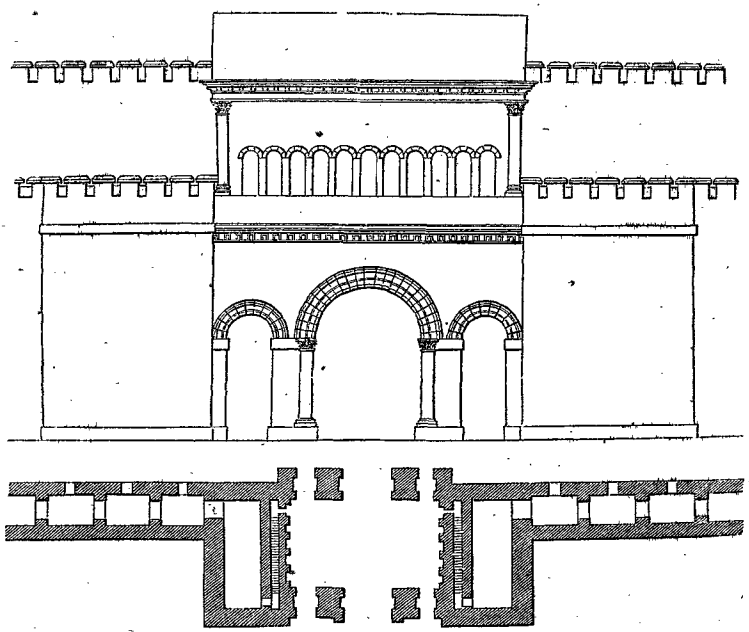


Fig. 106. GATE AT AOSTA.

sides have each two gates, and the others one, placed in such a position as to permit the streets to traverse in a parallel direction. The towers, built on the outside of the wall, are square, and placed at from 150 to 200 feet apart. The whole city was therefore contained in a parallelogram, whose sides were 2700 and 2200 feet in length.

The six gates resembled each other, and were defended by towers, in which were staircases to ascend the walls, the breadth of which at top was upwards of 20 feet. The three openings were closed with wooden gates, and above the archways, the wall, which was carried over them, was pierced with eleven semicircular-headed apertures, so that the guard traversing the walk behind the battlements could see who approached, or was about to enter or go out. (See *fig.* 106.) An architraved cornice surmounted the whole, bearing at each end upon a Corinthian pilaster. As the wall was double that surrounded the city, the space between was strengthened by arches, and the inner was carried up to a considerable height above the outer, both being surmounted with battlements.

Another fine example of a very early gate or entrance to a city is at Perugia, which has probably undergone very little change since the time of its construction. (See *fig.* 107.)

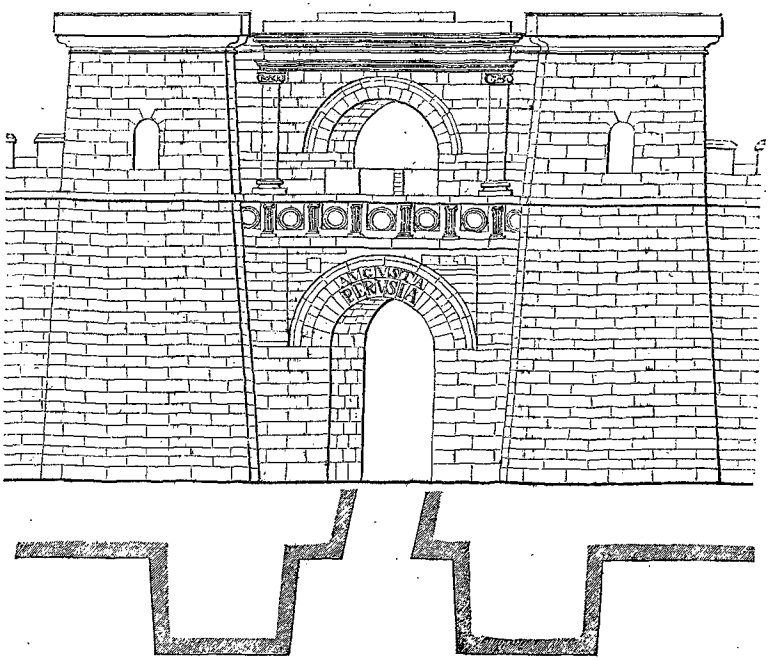


Fig. 107. PERUGIA.

The walls at Nismes, erected in the time of Augustus, are 30 feet in height, and, though varying in thickness, were generally about 9 feet; they are faced on both sides with regular courses of stone laid in cement; the interior is filled up with rubble, strongly united with mortar or cement as hard as the stone itself. The walls were covered with flags of freestone, which projected over each side; these flags were about 10 feet in length, and formed a platform for the movement of the soldiers engaged in the defence of the city: an external and internal parapet was constructed upon them. The towers were generally round, and the thickness of their walls 5 feet 6 inches, their interior diameter 24 feet 6 inches: they projected from the walls, as shown in the other examples.

At Nismes the gateways are constructed of stone; one has two entrances of the same width, each about 12 feet, and 20 feet high; on each side was a smaller for foot passengers, 6 feet in width and 14 feet in height; above the side openings are niches. A level cornice surmounts the whole, and terminates against the two round towers; above this was an attic, now destroyed. The towers are 31 feet in diameter.

Another gate remaining has only one entrance, 13 feet in width, and 21 feet in height.

The walls at Pompeii are usually rubble, faced with reticulatum, 20 feet in width, including the thickness of the two walls which crowned the ramparts: they varied

in height from 25 to 30 feet, according to the inequality of the ground: at unequal intervals, towers were built, 27 feet by 33 feet, which projected 7 feet from the outer face: their walls were 3 feet in thickness, also formed of rubble.

Embattled walls were raised upon the inner as well as outer edge of the rampart, that next the city being some feet higher than the other; these were formed of large stones 2 feet 6 inches thick, and each battlement had a return wall more effectually to protect the defender. Between these walls was a wide walk that passed through arched doorways made through the towers.

The outer walls of the towers have fallen; generally they were divided by a wall, for the purposes of strength, and arched over at the top, to allow the walk to continue uninterrupted around the battlements. The entrance to the city from Herculaneum consisted of an outer and inner wall, each having three arched openings, the space being left open to the sky: this was about 42 feet in extent, and 47 feet in depth. The lateral gates for foot passengers were two arched openings on each side. The centre was guarded by a portcullis about 7 feet distance from the face of the front wall.

In Italy, the south of France, and the towns scattered over Asia, may be found the walls and defences as set up by the Romans: they afford us the best commentary on the art of war, and the ingenuity practised by their engineers. A work of great interest might be compiled upon this fruitful subject; the architect would find study for the best construction, and the proportions which many of the entrance gates of these Roman cities exhibit are extremely beautiful.

The Gate of Augustus at Fano is a fine example of the entrance to a city, the lower portions of which are of great antiquity. Fanum Fortunæ was the name the city formerly bore, which, for its sumptuous buildings, was greatly admired. There are three entrances, flanked by circular towers, which rise to a considerable height, the two upper stories being lighted by semicircular-headed openings, and crowned with a bold projecting cornice,

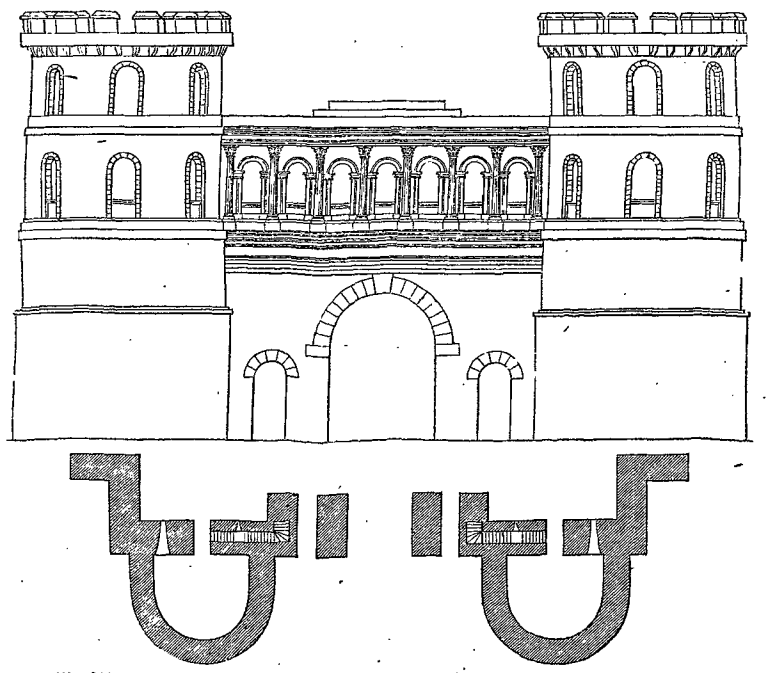


Fig. 108. FANO.

over which is the battlement. Immediately over the three entrances was a gallery, formed by seven arches, between Corinthian pilasters, and surmounted by a regular entablature. The repairs these walls underwent during the reign of Constantine somewhat changed their character, and since that period the upper story was destroyed by a cannonading which took place when this town opposed Julius II. Various inscriptions remain amid the several works of restoration.

The triumphal character of the entrance to a portion of the city of Autun, called St. Andrè, also deserves our notice. Most of the cities in Provence, and throughout the south

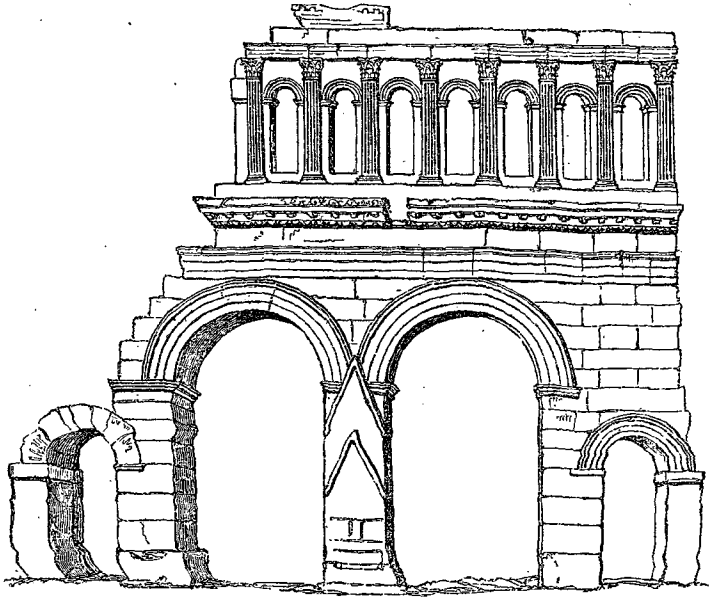


Fig. 109. GATE OF AUTUN.

of France, were embellished by the emperors at various times; and so similar in design and construction are these structures to those of the imperial city, that they cannot for a moment be considered but as erected by Roman engineers.

Architecture on some is more lavishly introduced than on others, and in that at Autun the Attic is beautifully proportioned and executed.

Distribution and Situation of the Buildings within the Walls. — The circuit being completed, the next work was to set out the streets, and mark the sites for the public as well as private dwellings. The Roman engineers are described by Vitruvius to have laid down first a marble pavement in the centre of the ground comprised within the walls; after they had made this smooth and polished, they raised upon it a brass gnomon; at the fifth antemeridional hour, the shadow that it cast was noticed, and its extreme point accurately determined. Around the gnomon was then described a circle, the radius of which was made equal to the length of the shadow. When the sun had passed the meridian, it was again remarked when the shadow of the gnomon reached the circle. From these two points on the circumference, two arcs were described, intersecting each other, through which intersection, and the centre of the gnomon, a line was drawn which indicated the north and south points. On the circumference to the right and left of the north and south points, one sixteenth part of the circumference was set out, and lines through the centre of the gnomon drawn to connect them; one eighth part of the entire area of the circle represented the region of the north, another the region of the south. The remaining portion was divided into three equal parts on each side.

The directions of these several lines mark out the wide as well as narrow streets; for it was considered that if they were set out parallel to the direction of the winds, the latter would rush through with greater violence, and that during a gale or strong wind, the angles of the different divisions of the city dissipated it, and prevented it doing any mischief to either the buildings or inhabitants.

When the city was near the sea, the Forum was placed close to the harbour; when inland, in the centre. The temples of the gods were mounted on an eminence that commanded the city: that of Mercury was established in the Forum; of Isis and Serapis, in the great public square; Hercules, near the Circus; Mars, out of the walls; and of Venus, near the gate.

Materials used in the Ancient Edifices of Rome. — The materials which the Romans employed were either for the purposes of construction or for ornament. The first, as lime, pozzolana, clay, and stone, the immediate neighbourhood furnished; those which luxury

called into use were brought from distant parts of Italy or the provinces, as the marbles, granites, and porphyries.

Vitruvius treats of bricks, but confines himself to the description of those which are unburnt. Scammozzi imagined that the houses in Rome were originally built of unburnt brick, and that none are found, he observes, is in consequence of the frequent fires that city was subject to, which had the effect of thoroughly burning them. Pliny (lib. vii. cap. 56.) mentions unburnt bricks as having been in use. Gellio Doxius, son of Cœlus, was the inventor of clay houses, taking the example from the nests of swallows. Burnt bricks came into very general use for public buildings about the time of Augustus, continued till the fall of the empire, and were considered as durable and solid as stone.

Bricks have undergone various changes, not only in form and colour, but also in the manner in which they were employed. In the time of Augustus, they were made of a red earth, less than an inch in thickness, of a triangular shape; they were not equilateral, as the base was the longest side. Such bricks may be seen in the gardens of Sallust, the house of Augustus, and other buildings erected in the time of Tiberius. In the prætorian camp at Preneste they were rather thicker, and of a deeper red colour, or mixed with yellow. In the time of Nero, these colours were generally united, as may be seen in the aqueduct constructed in his time, near the Porta Maggiore, where the bricks are somewhat thinner than those used in the time of Augustus or Tiberius; they were also thicker at the base, that the face might allow the edges almost to touch, and not show any joint or mortar. The walls, built of brick, by Augustus and Tiberius, show a joint of mortar almost equal to the thickness of the brick. Some remains of the Circus Maximus, under the Palatine, and on the Palatine itself, though of the time of Nero, have large joints, and are not so regularly laid.

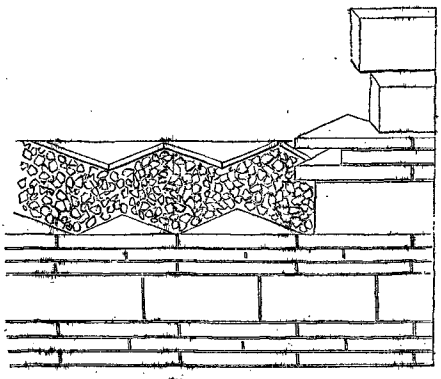


Fig. 110.

Of the time of Vespasian and his successors, we have brick constructions, as in the Coliseum, the baths of Titus, and the villa of Domitian at Albano, all of which have more of the Augustan workmanship than that of the time of Nero. The remains belonging to the time of Trajan, on the Quirinal, and called the baths of Paulus Emilius, and the villa of Adrian, prove that the same style was adopted. In the buildings constructed at the latter period of these reigns, bricks are mixed with the opus reticulatum; although there is an evident decline in the taste and execution of the ornaments in the time of Caracalla, the construction was excellent. One of the best examples is the wall at the back of the great central hall of that emperor's baths. After this period, the construction declined in excellence, bricks were made of various thicknesses, and the quantity of mortar was increased. There are scarcely any remains of brick construction between the times of Caracalla and Diocletian; the walls of Rome, usually attributed to Aurelian, probably belong to Honorius, as we learn from the inscription remaining over the gate of St. Lorenzo, as well as from a passage in Claudian, which affirms such to have been the case. The baths of Diocletian show a falling off, not only in style, but in construction, which rapidly deteriorated; in the basilica of Constantine, erected on the Via Sacra, in the time of Maxentius, and the baths of Constantine, on the Quirinal, we see still greater negligence in the selection of materials, with an inferiority of workmanship.

After this period, from economy, or desire to save bricks, a mixed construction of bricks and tufa was introduced, as in the restoration of the tomb of the Scipios, in the circus called Caracalla's, though of a date much posterior to that emperor; the ruins adjoining to that circus; and the hippodrome of Constantine on the Via Nomentana. The basilicæ and churches founded in the fourth, fifth, and sixth centuries, as those of S. Croce in Gerusaleme, S. Giovanni e Paolo, &c. &c., show the same poverty of construction, irregular bricks being used with quantities of mortar of an inferior quality. With the decline of Roman institutions, the art of construction lost its excellence; no care was taken in the selection of the materials, but those purloined from other edifices were indiscriminately employed. For bricks, they used stone of a similar shape, tufa, pepperino, and a variety of other materials; which practice was adopted at Rome in all the constructions till the end of the fourteenth century, and which has been denominated Saracenic work.

The bricks which Vitruvius describes as unburnt were formed of white earth or chalk,

and red earth or rough sand; which materials were preferred on account of their lightness. Other kinds, heavier, which do not adhere to the straw, or are dissolved by wet, were objected to. Bricks were made in the spring or autumn, as the drying then was more regular; those made during the summer solstice suffered injury from the heat, the interior seldom drying regularly, and their exterior hardening rapidly cracked. Those were the best which had been made two years; they were hardly considered dry before that time. Three kinds were used; by the Greeks called didoron, a foot long and half a foot wide, pentadoron, and tetradoron. Half bricks were made to work with them, which enabled the artificers to break the joint, and to have a vertical joint over the middle of the brick below. Some bricks were moulded of an earth so light that they would swim on water, as those of Calentum in Spain, Marseilles in Gaul, and Pitane in Asia.

Of Tiles and Conduit Pipes made of Clay.—The same earth used for making bricks served for forming flat and curved tiles, and different sorts of conduit pipes. Roofs were covered with alternate flat and curved tiles, and tubes or pipes were used to conduct water from them, as well as to convey it to the fountains. In the thermæ of Antonines, water was supplied to the baths by cylindrical pipes, gathered in at one end sufficiently to be inserted into the adjoining one; in the baths of Titus, square pipes were used for the same purpose. In the fountain of Egeria, long conical pipes, one end inserted in the other, are to be seen, which conducted the water from the aqueduct to the fountain.

Tiles, two feet square, with a small foot at each angle, were placed upright against the walls, at the baths of Livia, thus leaving between the face of the tile and the wall, pressed against, by the four feet, a narrow space, which prevented any moisture injuring the wall; they are fixed by T cramps of iron.

The Romans built hollow walls and domes, with pots and tubes of earthenware, which practice was continued down to the end of the middle ages; they seem, also, as we shall have occasion hereafter to observe, to have preferred earthenware pipes for their supply of water to those of metal.

The *Sand*, used in Roman construction, we find to have been obtained either from the pit, river, or the sea, as circumstances or convenience permitted. Several sorts were used, as black, white, deep red, and bright red; that which produced a grating sound, when rubbed between the fingers, is said by Vitruvius to have been preferred; that which was earthy, and which did not possess the roughness above named, was fit for the purpose, if it merely left a stain, or a particle of earth, on a white garment, which could be easily brushed away. The carbunculum, or bright red sand, was dug out of mountains of volcanic origin; it was of a much softer nature than tufa, but more solid than the common earth. The property which all sand has of hardening and consolidating with lime renders it of great value in construction; it has been observed, that the sand on the sea-shore, nearest the action of the waves, is the firmest and most solid, and this by the ancients was accounted for upon the principle, that the larger the masses the farther they were projected; for the hand cannot throw small bodies to a great distance, in consequence of their lightness. Several stones driven together on the sea-shore would also have the lighter particles of sand washed among them, and fill up their interstitial spaces, and thus form a consolidated mass. Between sabulum and arenam, as used by Vitruvius, there is a considerable difference: some writers observe that sabulum is a larger kind of sand, or arenam grossiorem. But arenam is not sabulum, one having the character of earth, the other of stone. Sabulum has a fine white or yellowish grain, is found in hot climates more than in cold and temperate ones, as in the deserts of Africa, where the surface of extensive tracts are agitated by the wind in the same manner as the sea.

Sea-sand was objected to for plastering, or for mixing with mortar, as it dried slowly; when dug from a pit, and exposed any length of time to the action of the weather, a vegetation was encouraged, which injured its properties, and rendered it unfit for use. River sand was always preferred on account of its grit, and was allowed to make the best mortar.

Lime, either burnt from white stone or flint, called by Vitruvius *silice*, was obtained, in all probability, from the same calcareous beds as the limestones of the present day, by the Italians called *palombino*. That which had a close and hard texture was preferred for mortar, and the lighter and more porous kinds for plastering. "When slaked for making mortar," Vitruvius says, "if pit sand be used, three parts of sand are mixed with one of lime; if river or sea-sand, two parts of sand are given to one of lime." Potsherds reduced to a fine powder and passed through a sieve were added: when river and sea-sand were used in the above proportion, the mortar was considered the best. The cause of the mass becoming solid, according to our Roman authority, was that sand and water added to lime formed an artificial stone, for all stones were supposed to be compounds of these elements; those which contained a quantity of air were of a soft nature, those which had a large proportion of water were tough, of earth hard, and of fire brittle. Stones which when burnt might make an excellent lime if pounded and added to sand, without burning did not possess the property of adhesion, nor set hard; passing through the kiln they lost their natural tenacity, and their pores were left open and inactive. The moisture and air

they contained were driven out, whilst a portion of heat was acquired and retained, which was dissipated by immersion into water. For this reason limestone was said to be heavier before than after it was burnt, and that it lost one-third of its weight, although in bulk it remained the same. The pores of limestone being rendered open by the expulsion of air and water, enabled the sand more readily to mix with and adhere to it.

Neither pure earth nor sand without lime could form a cement or mortar, or unite together polished bodies; and the Romans evidently well understood the method of preparing their lime, as well as mixing it with other materials for the composition of their mortars and cements: all the works left us in which these are employed, time has hardened into a mass equal in strength to the stone or tile which is imbedded.

Pozzolana, called a species of sand, or arenarium, is found abundantly in the neighbourhood of Rome, was used mixed with a proportionate quantity of lime to form a cement. The colour of Pozzolana varies, and the catacombs were probably formed by the extraction of this material. The ancient Pulvis Puteolana, mentioned by Vitruvius, was drawn from the neighbourhood of Pozzuoli, and its application may be seen in the ruins of Caligula's bridge in the port of Anzio, and in the mole of Pozzuoli. That found about Baiæ, when mixed with lime and rubble, would harden as well under water as in ordinary buildings, and this Vitruvius attributes to the heat of the earth, and the sulphur, bitumen, or alum, which the water holds in solution. Inward and subterraneous fires render this earth light and dry, but when moisture supervenes, the particles cohere in such a manner, that neither the waves nor the force of water can disunite them.

Spong or Pompeian pumice-stone, burnt from another species of stone, is acted upon by the fire in a similar way. Hot springs and heated vapours in the bowels of the earth were supposed to do what was effected in the lime-kiln, and that the moisture driven out was, when quickly supplied by water, able again to unite the particles in a more solid state than before, by means of the heat common to both bodies.

Some lands afford sand-pits in abundance, as the Apennines towards Tuscany, while on the other side none are to be met with; and some mountains are not earthy, but of stone. The force of the subterraneous fires, escaping through the chinks, burns that which is soft and tender: thus the earth of Campania, so burnt, becomes a powder, and that of Tuscany, which is of a harder quality, is converted into coal. Both of these materials are of great use, one being serviceable for constructions on land, the other for works under water. In Tuscany the quality of the material is softer than sandstone, but harder than earth, and constitutes that sort of sand called carbunculous.

Stones used by the Romans. — The practice adopted by the engineers of Italy of the present day, in the selection of their building materials, has not at all changed since the time of the republic: the territory of Bolsena and Stratone is still renowned for stone, which neither fire nor weather will affect; and a beautiful white stone, easily cut with the saw, and bearing a fine polish, is found throughout Lombardy, and applied in situations where frost cannot affect it. The limestones of Istria are used in Venice and elsewhere at the present day.

The ancients do not seem to have thoroughly understood the strength of the several qualities of stone; but were satisfied that no weight they could expose it to under ordinary circumstances would be too much for it to bear, or occasion it to crush; if in a mountain miles high it could carry the superincumbent weight, they had no fear of the result when used in a structure of ordinary height.

In the Campagna of Rome, a stone is found of a dark colour, which is easily worked, and resists both the action of fire and the atmosphere, but it has the peculiar property of absorbing all the water from the mortar or cement in which it is bedded, and therefore is only applicable to walls or constructions in a dry situation.

Most of the building stones readily obtained are those of recent formation, occasioned by deposits from water holding lime in considerable quantities dissolved by carbonic acid; these deposits gave the ancients the notion that stone grew: the banks of the river Neva so increased, that the valley became closed up and formed it into a lake, and in other situations masses of stone were seen to grow almost daily, from the deposit and evaporation of the water. Such stone is always soft when first cut from the bed, and hardens as the water it contains is evaporated from it. From the quality of the water many of the aqueducts became encrusted in a similar manner, and their channel considerably diminished.

The travertine, the tufa, the pepperino, and the gabina were used in foundations, for external walls, and for the filling in of walls and vaults. The selce was only used for paving streets, and the internal parts of walls; the pumice stone, from its lightness, for the construction of arches and domes. Tufa abounds in the neighbourhood of Rome, and particularly where the ancient excavations were made, beyond the Porta Maggiore, five miles from the Via Collatina, on the left. Strabo, lib. v. p. 164., describes this material as a volcanic product of a reddish hue, not very compact, and easily decomposed by the action of the air alone. In foundations we find it abundantly used, as on the Palatine hill, in the temple of Fortuna Virilis, and in the aqueduct of Claudius. When used for construction above ground, the exterior was covered with a coat of plaster: it was quarried in large masses.

Tufa was much employed for reticulated work, which style of construction came into use at the decline of the republic; and as there are few known examples of the time of Caracalla, it is supposed that during or after that emperor's reign it was discontinued. The pepperino is a volcanic production, found at Albano, by which name it is sometimes called; it is of a greenish brown colour, and the resemblance it bears to finely powdered pepper has given it the modern name. This stone, having undergone the action of intense heat, resists the action of fire, equally with that stone called gabina. It was on that account that Nero, after the great conflagration in his reign, ordered the houses to be faced with either one or other of these stones. Pepperino is more solid than tufa, and resists the action of the weather better; although to a certain degree it becomes affected. The walls of Servius at Rome are built with it, as may be seen in the remains near the Quirinal; also the walls which enclose the forum of Nerva, and the cell of the temple of Antoninus and Faustina. The gabina is a volcanic production, found near Gabii, distant ten miles from Rome. In colour it resembles the pepperino; it is harder, though of a more porous texture, and was much used for millstones. The travertine, or, as it was formerly called, tiburline, is found near Tivoli, on the banks of the Tiber; the ancient quarries remain, near the bridge of Lucano. This stone is calcareous, formed from the mixture of some sulphureous water with that of the Arno. It is very porous, resists the action of the atmosphere, and becomes harder the longer it is exposed: it is easily calcined by fire. In the Coliseum, the sepulchre of Metella, and many monuments in the Via Appia, this stone has been used; at first drawing from the quarry it is white, but the air acting upon it soon gives it a yellow tint, which increases by time: from its hardness it was used for plinths and substructions, for isolated columns, ornaments, cornices, capitals, &c. We see it in the Tabularium, the temple of Fortuna Virilis, the arch of the Goldsmiths, &c. It was ordinarily quarried in large quadrangular masses, and the smaller chippings were used for filling in.

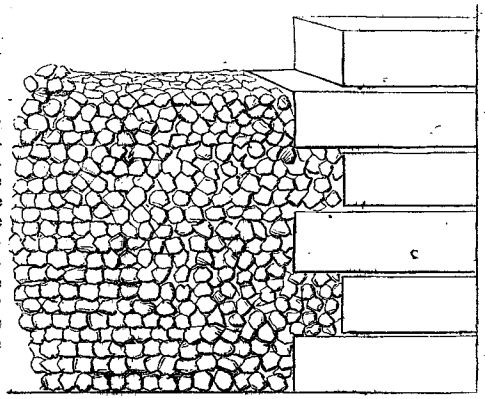


Fig. 111.

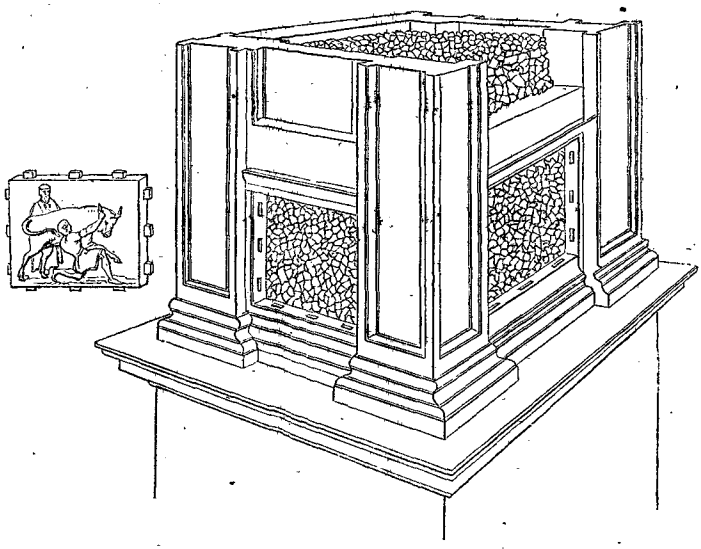


Fig. 112. ARCH OF THE GOLDSMITHS.

Siliceous stones, or what are called selce by the ancients, cannot be understood to mean the same as those so designated by mineralogists of the present day: those have an iron colour, are very hard, and are basaltic, and used only for street paving. Near the sepulchre of Cecilia Metella, on the Via Appia, and many other localities, it was abundantly found.

Pumice, brought from the vicinity of Vesuvius, was used in the vaults of the Coliseum, and in the palace of the Cæsars, the dome of the Pantheon, &c.

The most ancient edifices of Rome were constructed of the Albano stone, put together with metal cramps. Alba being the first important conquest made by the Romans, it was most likely they would employ the excellent material found in that neighbourhood, which had become a portion of their dominions, in preference to seeking for it out of their territory. This stone was used not only under their kings, but also after the decline of their republic. The Mammertine prison, built under Ancus Martius, and the Cloaca Maxima, under the Tarquins; the walls of Servius, remaining near the Quirinal; all that portion of the tombs of the Scipios not tufa, or which have not been restored; one of the three temples of S. Nicola in Carcere; the substruction of the Capitol; the aqueducts of Appius, Old Anio, and the Marcian, are all built of it. After the conquest of Tivoli, in the year of Rome 417, the travertine stone was introduced, and used in conjunction with that of Albano, and from its greater hardness was better suited to those portions of an edifice most

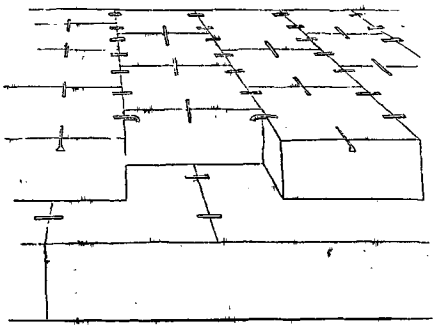


Fig. 113.

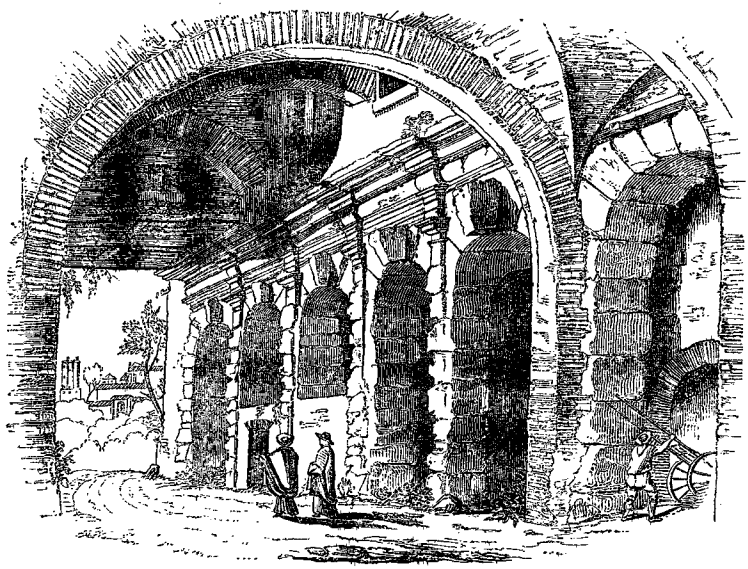


Fig. 114. VIVARIUM.

liable to injury, as arches, architraves, cornices, &c., as seen in the remains of the Vivarium. In the Tabularium we find it in the Doric capitals, the architraves, and imposts of the internal arches: in the temple of Fortuna Virilis the isolated columns are formed of it, as are also the Doric and one of the Ionic temples of St. Nicola in Carcere, the arch of Dolabella on the Cælian Mount, the façade of the Mammertine prison, which bears the name of the consuls C. Vibio Ruffinus and M. C. Nerva, who restored it.

Under the kings, and during the republic, it appears from the remains, that the public buildings were usually of squared stone (*fig.* 115.); but on the decline of the republic,

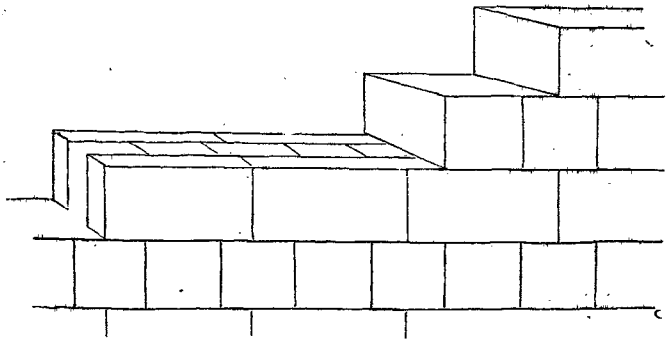


Fig. 115. SQUARED STONE.

that kind of construction called opus incerta prevailed, which must not be confounded with the work we see at Preneste, Cora, and other ancient cities of Latium. Vitruvius confirms us, and several ruins still show that the opus incerta was composed of small polygonal stones, set in mortar, specimens of which may be seen in a ruin behind the temple of Romulus, in the temple of Vesta at Tivoli, of Fortune at Prefleste, and in many other ruins scattered over the Campagna; whilst the walls of the ancient cities of Latium are formed of polygonal stones 4 or 5 feet in diameter, laid together without any cement. The opus incertum is the external coating of the wall, being backed or filled in with all sorts of material. (See *fig.* 116.)

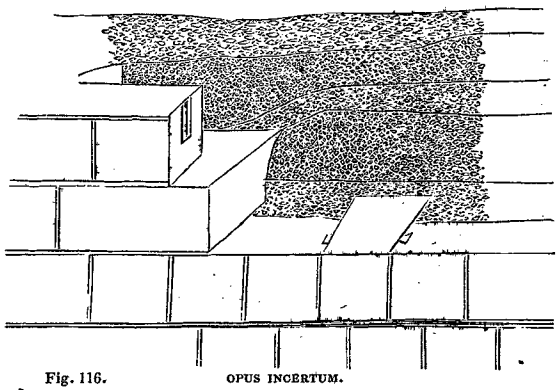


Fig. 116. OPUS INCERTUM.

To the opus incertum succeeded the opus reticulatum, which was in ordinary use at the time Vitruvius lived, and continued till the time of Caracalla. At the same time burnt brick was introduced.

The opus reticulatum (*fig.* 117.) has the stones formed like wedges, and put together to resemble the meshes of a net; the stones found in the country were used, whatever they might be composed of, and as the angles or quoins of their buildings could not be executed properly with them, they used for this purpose tiles, or brick, or stone of a rectangular form like them. In the gardens of Sallust at Rome, the house of Mæcenas, which afterwards served for the substructions of the baths of Titus, we see the opus reticulatum used promiscuously with brick.

Brick was early used for construction, became general in the time of Augustus, and continued in use till the fall of the Roman empire; it is as solid, and perhaps more durable, than stone.

Thus the Romans used squared stone during the time of their kings and the republic;

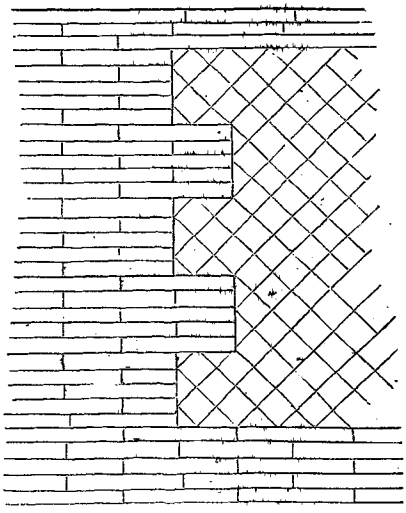


Fig. 117. OPUS RETICULATUM.

on the decline of the latter, and under Augustus, the opus incertum; the opus reticulatum, with and without brick, ceased to be used under the Antonines; and brick was afterwards employed alone to the end of the seventh century — though after the time of Constantine it was mixed with strata of volcanic stone, and took the name of Saracenic work. The brickwork, from the time of Augustus to Constantine, was formed of triangular bricks; at certain heights were introduced courses of square or rectangular tiles, which passed through the entire thickness of the wall, and bonded the whole together; this tied in the facing, called by the modern Italians, *cortina*. Such work may be seen in the baths of Antoninus, temple of Venus Erycine, and on the Palatine.

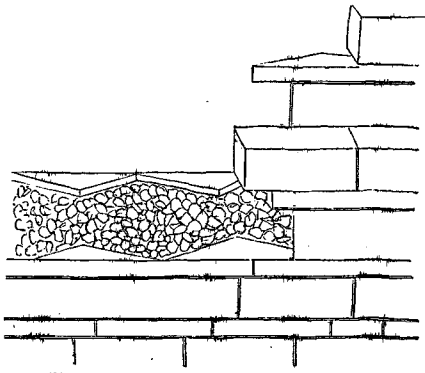


Fig. 118. BRICK.

Before stone was used for building, it was usual to expose it for two years to the action of the weather, and that which was most convenient to Rome was drawn, as Vitruvius says, from the countries of the Pallienses, Fidenates, and Albanæ; those which were soft after the two years' exposure were allowed to be used in the foundations; which perhaps would be contrary to modern practice; but the excellence of their cement compensated in some degree for this use of a friable material.

The principal Marbles were the *Carrara*, abundantly used in the structures of the imperial city, and also in the provinces. Strabo, who wrote in the time of Tiberius, observes, that at Luna, a city in Etruria, slabs of white as well as veined marble for tables, and shafts of columns in one single piece, were quarried; and the greater part of the edifices of Rome and other cities of Italy were enriched with it: it was easy to remove it from the quarries to the sea, from whence it could be freighted up the Tiber. This passage of Strabo leads us to suppose that most of the edifices after the time of the emperor Augustus were adorned with this marble. At the time of Pliny these quarries yielded a kind that surpassed the Parian in whiteness, and Mamurra, a Roman knight, decorated his house on the Cælian mount with columns of it, which was the first instance of its being so applied at Rome. The grain, though finer than that of the Greek, is not so pure a white when polished.

The marble brought from Hymettus, near Athens, was as celebrated as the Pentilican. Xenophon mentions them both as used by the Athenians for their temples, altars, statues, and other works. Strabo admires its beauty, and Horace intimates that he encrusted the walls of his house with it. It was employed at Rome, before any other foreign marble was introduced, for columns, and Pliny tells us that Lucius Crassus the orator brought six, not more than 12 feet in height, to decorate the atrium of his house on the Palatine, 91 years before the Christian era: for which reason it was called by Marcus Brutus the Palatine Venus.

The Pentilican marble, composed of white with greenish veins, was quarried in the neighbourhood of Athens. By the Roman writers it is seldom mentioned; by the Greeks it was held in high estimation, though not much employed in the buildings at Rome. Plutarch implies that the columns of the temple of Jupiter Capitolinus were formed of this marble, brought from Athens.

The Parian, found in the Isle of Paros, so much admired by the ancients, was chiefly taken from the quarries of Marpessa, and of a pure white; it was confined to the use of sculpture. Procopius tells us that the walls of the mausoleum of Adrian were covered with slabs of this marble, which no longer remain. It is also called Ligdino and Lienite.

The Proconnesian marble was white, diversified with black veins, sometimes proceeding in straight lines, often obliquely and winding; it was found at Proconneso, an island in Propontis: and at Cizicus it was used for building. In the time of Constantine, Justinian employed it for incrusting the walls of S. Sophia, as well as for the columns which adorned that building.

The Tatian marble, according to Pliny, was white and full of spots, and much used in the time of Nero and Domitian, after which we do not often find it employed. It resembles the Lesbian, but is clearer. Some have supposed the square blocks of the pyramid of C. Cestius to be of this marble, though they are more probably from the quarries of Luna.

The Fengite, called so from its pure whiteness and splendour, was first noticed in the time of Nero, at Cappadocia, and was employed by that emperor in the construction of the

Temple of Fortuna Seja, which formed a part of his golden House. Domitian had the walls of the arcades, through which he alone passed, inlaid with it, that he might observe what was passing behind him. This was possibly the Marmo Salino.

Of the coloured marbles, the most famous was that of Carystos, the modern Castel Rosso, a city of the Negropont; it has a greenish colour, with lines and undulations, resembling the waves of the sea: the quarries at Mount Ocha were called Marmarion: it was much used in Roman edifices, and was one of the earliest marbles introduced into that city, and became very common in the time of the emperors. The columns of the temple of Antoninus and Faustina are formed of it, and in consequence of their resemblance to the cipollo (onion) are called Cipollino. It was used also for pavements; the Basilica of Constantine, or temple of Peace, has slabs of it; there are many columns still among the ruins, and in modern churches, made of the Cippolino.

The Lacedemonian marble is of a green colour and very hard; it is found at Taigeto in Laconia, and its quarries were used in the time of Strabo under Augustus and Tiberius; it is likened by some to the emerald and to the verde antique; it bore some resemblance to the Thessalian, and from a passage in Pausanias we learn that at a village in Laconia, at the foot of Taygetus, quarries of marble or hard stone were worked, which being cut into form were polished by immersion in the river, and became so beautiful, that they were applied to adorn the temples of the gods. The marble we call serpentine is mentioned by Strabo, and is the ophite of Pliny. The qualities which the ancient writers quoted give to this marble agree with the serpentine, which is of a grassy colour and very hard, being especially adapted for tesseræ; such is that of the grotto of the nymph Egeria. Lampridius says that Heliogabalus lined the arcades of the Palatine with Lacedæmonian marble and porphyry, that is, serpentine and porphyry, a method improved upon by Alexander Severus, from whom it was afterwards called Opus Alexandrinum, and was in great use during the decline of the arts, most of the early churches being cased with it: one of the finest examples of which is that of S. Giovanni and Paolo, on the Cælian mount, which was decorated in the fourth century. The ancient writers mention that the Lacedæmonian marble was used for incrustation, but do not say it was employed for the shafts of columns: in the baptistery of the Lateran, before the chapel of St. John the Baptist, are two columns of red porphyry, of the Corinthian order, with capitals and bases of Lacedæmonian marble. Serpentine in small pieces is very common in Rome, and was much employed for pavement in consequence of its hardness. In the baths of Antoninus, the pavement was composed of small tesseræ, or coarse mosaic, of Lacedæmonian and Numidian marble, viz. serpentine and giallo antique.

The Atracian or Thessalian was another variety of green marble, obtained from the banks of the Peneus, 10 miles from Larissa. Paolus Silenziarius says it was a green marble, resembling the emerald, mixed with deep blue spots, a light black and snowy white, and was much prized by the Greeks. This is no doubt the verde antique, specimens of which are in the Basilica of the Lateran.

The marble of Chios, from the island of that name, is of various colours, the light black most predominating, resembling the African. The Arch of Drusus on the Via Appia has columns of this marble; they are also found in the Pantheon, and in the Basilica Ulpia of the forum of Trajan, which was partly paved with it.

The Phrygian marble, called *Pavonozzetto*, very much esteemed, was found near Docimea in Phrygia. It is white, with purple veins. Twenty-four columns of this marble decorated the Basilica of Paulus Emilius in the Roman forum, and now form the chief ornament of the Basilica of Ostia. This marble is common at Rome, being found in almost all the churches. The figures of the Prisoner Kings on the arch of Constantine are made of it, as are the statues found among the ruins of the forum of Trajan. From a passage in Strabo we learn that quarries which at first only yielded small masses of this marble afterwards produced columns of one block, and notwithstanding the distance from the sea they were transported to Rome. During the decline it was used in the decoration of the churches, particularly by Justinian at S. Sophia at Constantinople.

The Lydian marble was of two kinds, one red mixed with a pale colour, which we now call red brescia; the other black, called by the ancients basinite and chrysite, both found in Lydia, a province of Asia Minor.

Nero Antico, or black, quarried at Tenarus, a promontory of Laconia, has a beautiful surface, and is at the present day highly prized. Columns of it at Rome are to be met with as early as the time of Augustus, at which time it was much used in Greece.

Of the Timber used by the Romans. Great attention was paid in the selection of timber for construction, and all belonging to the fir species were usually cut down when they put forth their young shoots, that the bark might be more readily stripped. The maple, the ash, the elm, the lime, and the oak were felled in winter, the latter being considered subject to worm if cut down in the summer. Vitruvius prefers the autumn for felling of timber; for the fruits being ripened, and the leaves dry, the roots draw

the moisture from the earth; the trees, he says, are then recovered from their exhaustion, and restored to their pristine solidity. In felling them, he recommends cutting through the trunk of the tree, then leaving it for a time to allow the juices to drain off, by which means future decay is prevented. When the tree has drained sufficiently, it may be cut down and applied to building purposes. Hesiod says, when the trees shed their leaves is the proper time for felling.

Oak, elm, poplar, cypress, and fir were all used for building, and the holm oak, or esculus, was greatly preferred. The green oak (*cerrus*), the cork tree, and the beech were considered liable to rot, which was accounted for by their containing equal quantities of water, fire, and earth, which rendered them incapable of balancing the quantity of air they contained. The white and black poplar, the willow, and the lime tree (*tilia*) were also used. The alder was selected for piles, as it was found not to decay under water. The city of Ravenna had its foundations entirely on such piles. The larch, growing on the shores of the Adriatic and banks of the Po, was considered not subject to decay, and consequently was highly esteemed; it had considerable density, and would not float in water. Julius Cæsar first called it Larigna, or larch, after the name of a fortress constructed entirely of this timber near the Alps, which, when besieged and surrounded with bundles of fire-wood and torches, was not ignited. A wood that would not burn was considered admirably adapted for the plates and rafters of dwellings, as they would neither ignite nor become charred. It was brought down the Po to Ravenna, and used at Ancona, &c.

The palm possessed the peculiar property of bending upwards when any weight was placed upon it; and the juniper, said by Pliny to have the same properties as the cedar, and to be even more durable, was also used. The olive was greatly esteemed, as was the wood of the box tree; for exterior works the chestnut was much employed; for the fittings of houses, for tables, benches, &c., the fir, as was the pitch pine and cypress; for thin planks, the beech was in general preferred to either the chestnut, the elm, or the ash. The mulberry was considered durable, and admired for its getting blacker by age. Cato advises, for the making of levers, holly, laurel, and elm to be employed; for bars, the wild cherry tree, or the corneil; for stairs, the wild ash or maple; for water pipes, the pine, the pitch tree, and the elm, which were buried entirely in the earth to prevent decay. For the use of the turner, they selected beech, mulberry, and the box, as well as ebony. Poplar was employed for statues, as was the hornbeam, the service tree, the elder, and the fig; these, from their dryness and evenness of grain, were easy to work, and fitted to receive the colour they were to be finished with. Woods which differed in quality were seldom brought together, as it was supposed that those which were of a hot nature could not be united by glue to those grown in moist and cold places; wood of a close texture and fine grain could not be glued together, and oak was said to be unique in this particular, as it would not unite with itself, or any other wood of the same nature. The ancients, as Vitruvius advises, did not glue planks of beech and oak together, considering that woods differing so much could not be firmly united. All this is owing to the unequal shrinking of the several kinds, which must, whenever it takes place, detach the planks brought together; were both equally dry, the one would absorb more moisture than the other, swell or expand in proportion, and have also a tendency by this action to detach itself.

Pavements, when used for floors, were very highly decorated, much attention being required to prepare the soil to receive them, and to select the material of which they were formed. When on the ground, it was carefully examined, and rendered solid

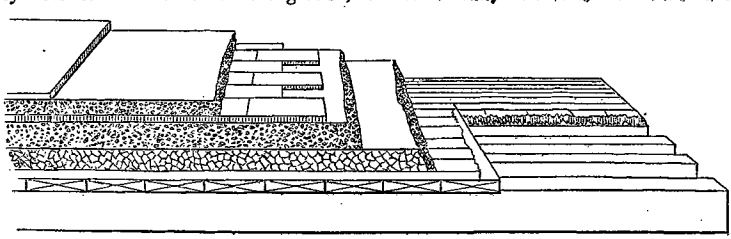


Fig. 119. PAVEMENTS.

throughout, after which it was spread over with a layer of some dry material. When laid upon a timber floor, walls were not built under it, but a space left between it and the floor, that the drying and settling should be equal throughout. Holm timber was preferred to oak, less likely to split and warp, and thus cause cracks. After the joists were laid, thin boards were fastened down to them by two nails, driven through the edges of each, which prevented their rising. Fern or straw was then spread over the whole, to prevent the lime coming in contact with the timber, which would have immediately

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caused it to decay. Over this was a layer of rubbish, the stones of which were as large as would lie in a man's hand: on this layer the pavement was afterwards laid. New rubbish required that every three portions should be mixed with one of lime; and old, five parts to two of lime. Wooden beaters were employed, which by repeated blows reduced it to the thickness of nine inches. An upper layer, composed of three parts of potsherds and one of lime, was spread over this to a depth of six inches, on which was laid the slabs of marble, stone, or tesseræ, care being taken that the whole should lie in a proper inclination: it was then rubbed off, and the joints or edges of the ovals, triangles, squares, hexagons, or other figures, made perfectly smooth. After rubbing and polishing, marble dust was strewed over; then lime and sand run into the joints.

Pavements in the open air had over the first flooring another layer of boards crossing them, properly secured by nails, so that the joists were doubly covered. The pavement first laid was composed of two parts of fresh rubbish, one of potsherds and two of lime. After the first layer, a composition was spread over it, pounded into a mass, not less than

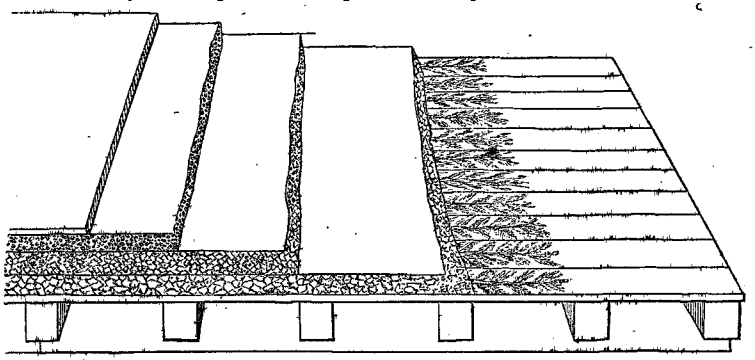


Fig. 120. PAVEMENT.

twelve inches thick. The upper layer being spread, the pavement, consisting of tesseræ, each about two inches thick, was laid on, with an inclination of two inches to ten feet, to prevent the frost from injuring it at the joints: before the winter it was saturated with dregs of oil. When great care was required, the pavement was covered with tiles two feet square, properly jointed, having small channels an inch in depth cut in the edge on each side. These, filled with lime, tempered with oil, had the edges rubbed in and pressed together. The lime in the grooves or channels growing hard, neither water nor any thing else would pass through. After this precaution, the upper layer was spread and beaten with sticks; over which, either large tesseræ or angular tiles were laid with the proper inclination.

Tempering lime for stucco received considerable attention, that the lime should be of the best quality, and prepared long before required for use. When lime was not thoroughly slaked, and fresh from the kiln, it was found to blister, and destroy the evenness of the stucco. After it was properly slaked, and laid in a heap, it was chopped with a hatchet, when, if any lumps appeared, it was considered not sufficiently slaked; when the iron of the instrument used came out dry and clean, the lime was considered poor and weak; but if it had any glutinous substance adhering to it, it indicated richness, and that it was thoroughly slaked, and properly tempered. This was used to form the compartments and last coat of the walls.

Stucco work, for arched ceilings, was executed by setting up parallel ribs about two feet apart, made of cypress, it not being so liable to rot as other woods. These ribs were cut to fit the curve, and secured in their place by iron nails: being fixed, Greek reeds, previously bruised, were tied to them in the required form, with cords made of the Spanish broom. On the upper side of the arch a composition of lime and sand was laid, to prevent any water, that might fall from the floor above, penetrating through it.

When Greek reeds could not be obtained, common reeds were used, tied together in bundles of appropriate lengths, but of equal thickness, observing that between each two ligatures there should not be a greater distance than two feet. These were bound with cord to the ribs, and made fast with wooden pins. The remainder of the work was performed as before described. The arches being prepared and interwoven with the reeds, a coat was laid on the under side. The sand was afterwards placed on it, and then polished with chalk or marble. When the vault was polished, the cornices were run over the springing, which were made as light as possible. A small quantity of plaster only was used, and the stuff was of a uniform quality, such as marble dust; plaster was apt to set too quickly.

When the cornices were completed, the first coat was laid on the walls as roughly as possible, and while drying, the sand coat was applied, setting it out in the direction of its length, by the rule and square, and attending to the perpendicular lines at the angles. After these two coats were thoroughly dry, a third was laid on, and its perfection greatly depended on the soundness of the sand coat. Sometimes three sand coats were laid on, and over them the coat of marble dust, which was so prepared, that when used it did not stick to the trowel, but came off the iron easily. Whilst the stucco was drying, another thin coat was well worked and rubbed, and then another still finer than the last. Three sand coats, and the same number of marble dust coats, rendered the walls solid, and not liable to crack.

When the work was well beaten, or hand floated, the under coats made perfectly solid, and afterwards smoothed by the hardness and whiteness of the marble powder, any colours put upon it exhibited great brilliancy. Colours, when used with care on damp stucco, do not fade, but are very durable, as the lime, deprived of moisture by burning, becomes porous and dry, and readily imbibes whatever is placed over it.

The Greek plasterers, Vitruvius continues, not only made their work hard by this means, but after the plaster was mixed, caused it to be beaten with wooden sticks by a number of labourers, before they used it. Slabs were often taken from the walls so plastered, and used for tables, it being thoroughly hardened.

When stucco was applied to timber partitions, the spaces were filled in first with clay, over which reeds were nailed, side by side, then a coat of clay, and another layer of reeds nailed on the former, but crossed in the opposite direction, one being upright, the other horizontal: after this the work was proceeded with in the usual way, finishing with the sand and marble coats.

Stucco works in damp places. Every precaution was taken to guard against the damp or moisture creeping up or passing through a wall; and Vitruvius is very particular, though perhaps not perfectly clear, in his description of the manner in which this was to be effected.

When apartments were on the ground floor, the walls, to the height of three feet from the pavement, had a rough coat of mortar spread over them, which was composed of potsherds instead of sand, to keep out the damp. When continual moisture was dreaded, a thin wall was built within-side the outer, at as great a distance as was possible, leaving a space or cavity for the air to circulate freely through. Openings were left both at top and bottom to assist this circulation, and prevent its becoming stagnant; the wall was afterwards plastered with potsherd mortar, and finished with the last coats. When space was an object, another mode of construction was practised: within the outer wall a channel was formed, having its ends open to the outer air: on the inner wall of this channel small piers were built of eight-inch bricks, on the outer edge of the channel, and on these small piers were laid two-feet tiles, a palm distant from each other. Over these flat tiles, square bent tiles, edge to edge, were fixed upright from the bottom to the top of the wall, the insides of which were previously coated with pitch, that any condensed vapour might not be absorbed, or penetrate the tile. These square tiled flues were open both at top and bottom, and on the side towards the apartment they were lime-whited over, to make them adhesive to the first coat of plaster, which from their dryness in burning they would not readily have done. The first coat being laid on, the coat of pounded potsherds was spread, and the remainder finished in the ordinary way.

The pavements of their rooms were carefully formed: first, they took out the ground to the depth of two feet, well rammed the bottom, and spread over the whole dry rubbish or potsherds, giving the work a fall towards the drain. On this was laid a composition of charcoal, lime, sand, and ashes, six inches in thickness, made perfectly level and smooth. This became hard and solid, and admitted of being rubbed with stone, and polished, when it acquired the resemblance of a black pavement. "Such," says Vitruvius, "is not only easily kept clean, but persons walking over it with bare feet are not likely to take cold."

The marble used in plastering, and which produced such a fine stucco, was not calcined, but simply pounded; the chips, left by the masons, were selected for the purpose; these, after being reduced to powder, were passed through three varieties of sieves; the larger particles were used with the sand and lime, then the second in order, and afterwards the finest; the work was then polished, and made fit to receive the colouring.

The colours used by the Roman painters are vivid even at this day; among them was red ochre, brought from Sinope in Pontus, Egypt, and the Balearic islands, near the coast of Spain, and many other places; green chalk from Smyrna; orpiment from Pontus; red lead from Pontus; vermilion from the Cilbian fields of the Ephesians. This latter colour peroxidises, and in consequence, immediately after it was used, and sufficiently dry, it was covered with a mixture of Punic wax and oil, put on with brushes, and afterwards made to lie in an even manner, by heating the wall, which was done with live coals inclosed in an iron pan; the whole was then rubbed with rolls of linen cloth.

Lamp black, of the best kind, was formed by burning the lees of wine in a furnace, and

grinding it with size; the common sorts, used by plasterers, was charcoal obtained from burning pine branches, pounded in a mortar with size.

Blue was thus formed:—sand was ground with sublimed sulphur, until it acquired the fineness of flour; to this coarse filings of Cyprian copper were added, and the whole, by the addition of water, made into a paste, rolled into balls, and afterwards dried; they were then put into an earthen vessel, and placed in a furnace, when a blue colour appeared.

A purple was obtained by plunging a lump of yellow earth, heated red hot, into vinegar.

White lead, verdigris, and red lead were in common use: purple was obtained from marine shells, which afforded the scarlet dye; the shells were collected, and broken into small pieces with iron bars, when the purple colour, which oozed out like tears, was collected into mortars, and ground. Madder root was employed to tinge chalk, and green was formed by mixing blue with the herb weld.

The houses at Pompeii are usually constructed of a great variety of inferior material, and on the strength of the mortar depended their stability; the walls were coated with plaster, formed precisely after the method described by Vitruvius. After the rough coat, a second, composed of sand and lime, called arenatum, and then the marmoratum, composed of sand and pounded marble, which was put on very thin, and rubbed and polished until a surface was obtained equal to marble. Whilst this coat was in a humid state, the colours were laid on, which, according to our author, incorporated themselves with the incrustation, and were not liable to fade: three coats of arenatum, and as many of marmoratum, were used in the best works, which received a polish capable of reflecting objects.

Strength of building. When lintels or beams are loaded, they are apt to sag in the middle, and cause fracture in the work above; but when posts are introduced, properly wedged up, this is prevented: by the insertion of two inclined pieces of timber, it may also be acomplished. (Vitruvius, lib. vi. cap. 11.)

The weight of the wall may be discharged by arches formed of wedges, concentrically arranged; these, turned over the beams or lintels, relieve the weight, and prevent them from sagging. In all buildings where piers and arches are used, the outer piers are to be made wider than the others, that they may resist the thrust of the arches.

Where walls were constructed to resist the pressure of a bank of earth, their thickness was proportioned to the weight they had to resist, and buttresses were added, which were placed as far distant from each other as the height of the wall, and made of the same width; they projected at bottom as much as the wall was thick, and gradually diminished to the top. On the inside of the wall, towards the mass of earth, it was indented like the teeth of a saw, which teeth were made to project from the wall as much as its height; the pressure of the earth was thus distributed over a larger surface.

The Romans sometimes formed walls entirely of rubble, or blocage, as it is termed by French writers; depending entirely upon the goodness of the mortar for their strength,

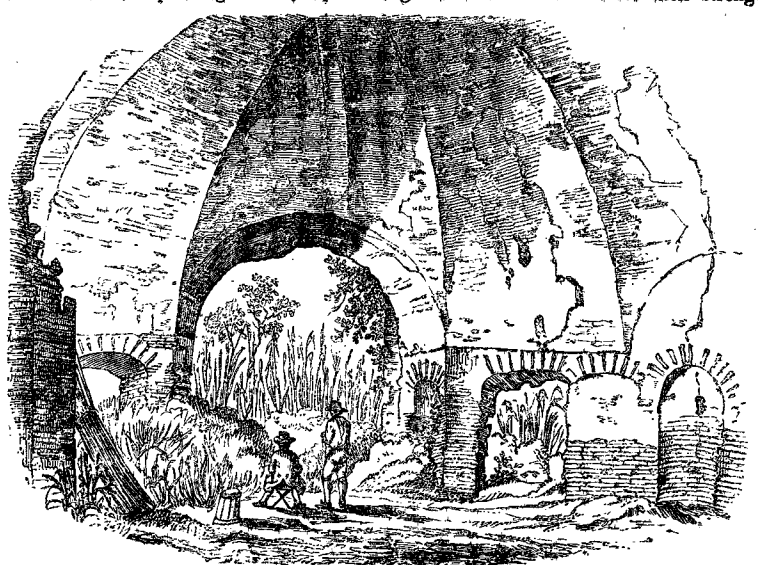


Fig. 121 MINERVA MEDICA.

small, irregular formed stones were thrown together, without any apparent order. In the large vaults of the baths of Caracalla, a species of porous lava was used, which was as light as pumice-stone. The vaults of the baths of Diocletian, the Coliseum, and the temple of Minerva Medica, are so constructed. These vaults, as well as those of Caracalla and the Villa Adriana, were turned on centres, formed of boards laid longitudinally, the marks of which may be seen where the stucco which finished their soffites has peeled off. On the boards was first spread a thickness of mortar of more than a foot, on which was laid flat tiles 2 inches in thickness, and nearly 2 feet square. These tiles were covered by others, and a second layer of mortar, but not so thick; the tiles were about 8 inches square, and $1\frac{1}{2}$ inch in thickness, laid in courses in such a manner as to break joint with the first layer.

Of the Forum and Basilica. No city of the Roman empire, however small, was without its place of assembly and its market for the sale of all sorts of goods. The forum was originally intended for this purpose, and was surrounded by a colonnade, over which was a gallery or covered portico, from whence the gladiatorial shows might be seen, which were exhibited before the introduction of the amphitheatre. Trades were carried on under its porticoes, and at the end of it was the senate-house; the curia, where meetings on solemn and religious matters were held, the comitia for the common people, the treasury, and other public buildings, adjoined it. Such was the Roman forum, and that at Pompeii, the size of which was proportioned to its population: its width was usually two-thirds its length; the columns of the upper colonnade were made one-fourth less than those below, following the order of nature, which in the fir, cypress, and pine, preserves a gradual diminution throughout their height.

The basilica, in which all legal business belonging to the city was transacted, had its precise form and arrangement. Vitruvius, who constructed one at Fano, gives its distribution, and describes what is necessary for its interior.

The middle vault between the columns was 120 feet in length, and 60 feet in width; the portico, or space between the outer wall and columns being 20 feet in width. The height of the columns, including their capitals and bases, 50 feet, and their diameter 5 feet.

The columns in the direction of the breadth of the vault were four in number, and on the side which joined the forum eight, including those at the angles in both cases; on the opposite side there were six, because the two central were omitted, that the view of the Pronaos of the temple of Augustus might not be obstructed. The tribunal was in the form of the segment of a circle, the width being 46 feet, and the depth 15 feet.

The two-fold direction of the roof, Vitruvius states, produces an agreeable effect on the exterior, as well as from the lofty vault within; and for economy such a building would always be preferred, no arrangement affording greater accommodation, with the same quantity of material used in its construction.

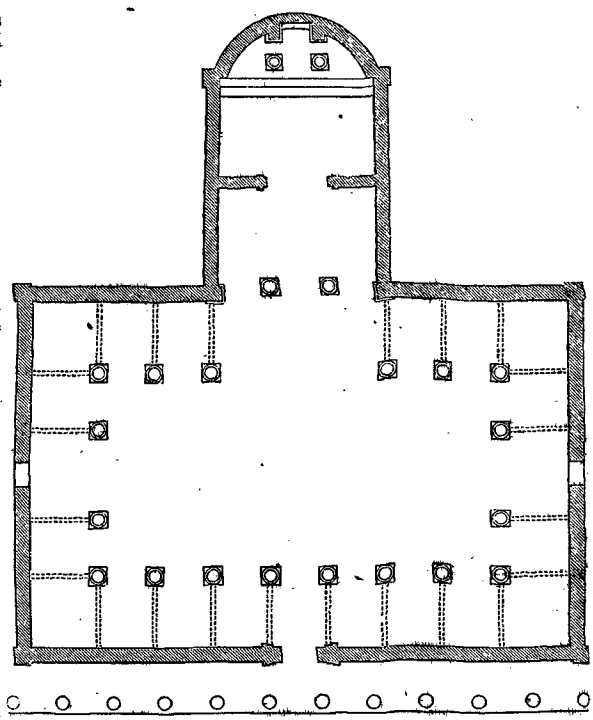


Fig 122. BASILICA AT FANO.

Numerous basilicæ remain to attest the truth of his descriptions, which at Rome now serve for churches: their form, being convenient for the assembly of vast numbers, has been

imitated down to the present time, in all buildings erected for that purpose. The examples at Pisa show how admirably adapted it was for the Catholic worship, and the Norman and Saxon ecclesiastics continued to make use of such models for whatever new erections they undertook.

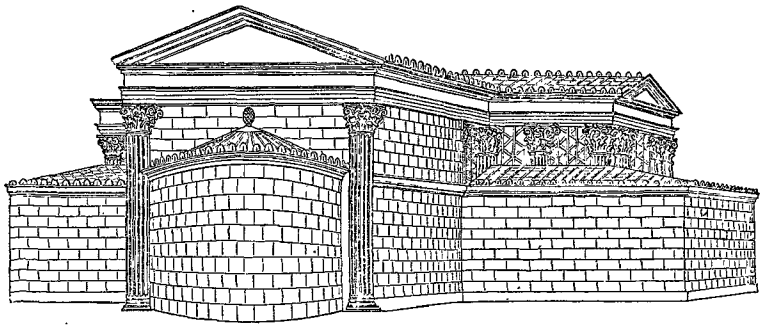


Fig. 123. BASILICA AT FANO.

The basilica, which adjoined the forum, in the Augustine age, was of the greatest importance: whatever was imposing in architecture was applied to it. The forum, graced with porticoes, statues, temples, triumphal arches, was by the citizens made their common place of resort, to which in time were added libraries and places of amusement.

Of the Theatre. The extent of some of the theatres which remain, and the manner of constructing them, deserve some attention, as they were first cut out of the sides of a hill, the proscenium being added to suit the locality, which required great skill on the part of the engineers who excavated them. In the early examples, the seats were cut out of the solid rock, and, from the convenience they afforded for the assembly of numbers, were often used for other purposes than the drama. The seats, elevated one above the other, afforded the spectators an opportunity of viewing the country, which rendered it necessary in after times to limit their vision to the theatrical representations, when the whole was inclosed within a lofty wall. Vitruvius tells us how these buildings were set out: — within a circle was inscribed three squares, the angles of which were to touch the circumference; that square, the side of which was nearest the scene, and which cuts off a segment of the circle, marked out the extent of the proscenium, and another line drawn parallel to this last, and forming a tangent to the circle, determined the front of the scene. Through the centre a line was drawn parallel, which separated the pulpitum of the proscenium from the orchestra. In the orchestra, the seats for the senators were placed, and the other portions of the theatre were so divided, that the angles of the triangles, which touched the circumference, pointed to the directions of the ascents, and steps between the cunei, on the first precinctories or stories. Above these the seats were placed, which formed the upper cunei, in the middle of those below. The angles pointing to the staircases were seven in number, the remaining five, marked the points of the scene; that in the middle, the royal entrance; those on the right and left, for the attendants. The seats on which the spectators sat were not less than 20 inches, or more than 22 inches in height, and their width from 24 to 30 inches. All the spectators were so situated, that they saw equally well, and the voice of the actor was heard by all. The seats were so arranged, that a cord drawn from the lowest to the highest touched the edge of each; and at the top a covered portico sheltered the spectators during the intervals of the drama from the heat of the sun.

The Proscenium was adorned, towards the theatre, with columns, niches, and statues; the stage was formed of wood; beneath which were various machines for adapting the scenes, and imitating thunder. Painted scenes, and triangular slips, which could be turned round, with devices upon them, and a quantity of machinery of various kinds, were introduced, to heighten the effect of the representations.

The top of the scene was level with the roof of the portico, so that the voice was distinctly conveyed to those on the upper seats.

Behind the scenes were porticoes, which, in case of sudden showers, might be resorted to, which communicated with verdant and pleasant walks, dug out and drained to the lowest possible level; to the right and left, sewers were constructed, which served for this purpose. The walks were carefully formed, taking out the earth to a certain depth: the space was filled with charcoal, on which a layer of gravel was spread, and Vitruvius tells us that in a time of siege, these walks were sometimes opened, and the charcoal taken out, and divided among the inhabitants. thus they contributed to health during peace, and preservation in the time of war.

Every city had its theatre, fragments of which remain. Herculaneum and Pompeii possess them in a tolerable perfect state: that of Marcellus at Rome, Arles, Orange, and other places in France, attest their grandeur and excellent construction; every attention was paid to the approaches of their seats, and to the shelter and protection of the assembled multitudes during a heated atmosphere, or inclement weather. Drains were contrived on each story, which below assumed the character of sewers, maintaining their cleanliness and comfort; all the rain that fell was collected by earthenware or metal pipes, and carried to the several conduits, studiously and carefully built up within the outer walls and inner piers. Sicily, and the provinces generally, boasted, according to their population, of a well arranged place for theatrical amusement. It became, at an early period of the Roman empire, as necessary an appendage to the city as the forum.

The Greek Theatres were also formed by excavating the side of a hill: a vast number of these are remaining in Asia Minor; and the only part constructed, or built from the foundation, is the wall of the scene. Many of the Roman theatres differ in their construction: being built with walls radiating to a centre, and arched from one to the other, to support the inclined plane, on which the marble seats were placed for the spectators. Between these walls all the spaces which were not left for communication from the several corridors were occupied by staircases, which served to mount to the precinctories, and for the egress of the spectators after the amusements were over, or during the intervals which were allowed between the performances. These buildings, erected for the accommodation of the people, were the result of the munificence of individuals; and in the smaller provinces, distant from the seat of empire, there seems to have been frequently a difficulty in completing them. The citizens of Nicea, after having expended a considerable sum in the erection of one, could not terminate it, as we learn from one of Pliny's letters to the Emperor Trajan. Augustus and Tiberius enlarged two theatres at Antioch, by adding a zone, or range of seats to the upper part of the structure: the former emperor, at his own cost, erected a very large theatre at Laodicea, placing in it a statue of himself in marble.

At Rome, in the first instance, these structures were of wood, raised at the expense of ediles, or other candidates for popular favour, and repaired or renewed as occasion required. Pompey, Balbus, and Marcellus were the first to build them of stone; and their use seems to have been for the exhibition of gladiators, more than for the drama. Suetonius, in his life of Augustus, says, that women were admitted to the upper porticoes to see the games; but that afterwards, it not being thought decent that they should be present, they were prohibited from entering. These regulations were soon laid aside, as we learn from the sixth satire of Juvenal.

Of the Theatre of Marcellus little now remains: twelve or thirteen arcades, with their Doric columns and entablature, and as many above of the Ionic order, which formed a part of its magnificent exterior, is all that can be seen. It is of Tiburtine stone, and the profile of the orders is well proportioned and executed. Augustus is said to have raised it in honour of his nephew Marcellus; when dedicated, six hundred wild animals were sacrificed; and for the first time tigers were exhibited confined in cages. It was a semicircle, the diameter of which, probably, from out to out, was 270 feet; one half of this radius was applied to the walls and corridors, over which were the seats, and the other to the orchestra; the dimensions given to the proscenium, as well as its arrangement, are not at present known. The building seems to have been set out very regularly, judging from what remains in the palace of Savelli Orsini, and from the plans left us by the architect, Baldassare Perruzzi of Sienna, who built the latter.

An outer and two internal corridors sweep round semicircularly, and on the outside were forty piers with 39 arches. From the inner piers, diverging to the common centre, were 40 walls, constructed as those of the Coliseum, though not with the same material.

The Theatre at Arles was a semicircle of more than 300 feet in diameter, and the proscenium had a depth of at least 180 feet: its exterior had three orders of Doric pilasters with arches between, surmounted by a bold modillion cornice; it was built of large masses of stone, in regular courses. Like the Coliseum, it had two outer corridors, and the walls diverging from a common centre composed the stairs, vaults, and vomitories, arranged in a similar manner.

The Amphitheatre was formed of two theatres, or semicircles united in such a manner that the spectators had an equal view of what passed in the arena: for which reason the Romans gave them the name of *visorium*: they were used for gladiatorial shows, combats of wild beasts, and other games. They were of large dimensions, made in the form of an oval: the arena or middle space was surrounded by rows of benches elevated one above the other.

The Etruscans introduced amphitheatres and gladiatorial shows: the Romans borrowed from them this taste, which degenerated into a fury among that warlike people, with which they inspired all the nations they subdued. The remains of amphitheatres are met with throughout the Roman empire. The first were probably mere excavations, the spectators being elevated on banks of earth; the more persons they wished to accommodate,

the more necessary it was to deepen the area: this may be seen at Pæstum, which also shows the manner of construction adopted when formed on the side of a hill; one half of the seats being on the natural slope, and the upper portions being raised on constructions. This method, from its economy, was perhaps the earliest; and thus the first theatres, as already observed, were formed out of the sides of rocks and hills. The seats were afterwards made with planks, and removed when the shows were concluded. This being found inconvenient, others were constructed in a more solid and substantial manner: many having been destroyed by fire, stone was at last resorted to. The first amphitheatres at Rome were temporary structures, and situated in the Champ de Mars, without the city. Statilius Taurus erected the first of stone, A.U.C. 725, which, with the Coliseum, were the only two within the walls.

The amphitheatres of Castrenses, erected by Tiberius, on the Esquiline hill, of which some remains are still seen, near S. Croce in Jerusalem, was built of brick, and of the Corinthian order. Another built by Trajan, in the Campus Martius, was destroyed by Adrian.

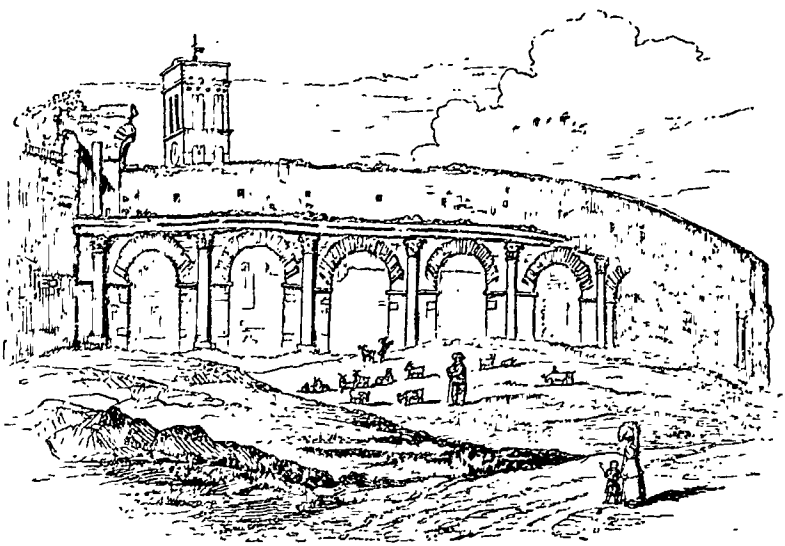


Fig. 124. CASTRENSE.

Nothing gives us a higher notion of the knowledge possessed by the Romans in the arts of construction, than the numerous and vast remains of their amphitheatres, erected in almost all their towns and provinces.

At Fedena, five miles from Rome, Attilus built an amphitheatre, in which, in consequence of the foundations giving way, 25,000 persons perished.

At Placentia was one of the largest in Italy, built of timber, without the walls of the city. At Arezzo, Florence, Fisole, Adria, Lucca, Palermo, Cassano, Minturno, Benevento, Alba, Capua, Pompeii, Puteoli, Otricoli, Catania, Agrigentum, Syracuse, Pæstum, Pola, Nismes, and Verona, Frejus, Arles, Autun, Saintes, Bordeaux, Orange, Narbonne, Die in Dauphine, Cahors, Drenaül on the Cher, Toulouse, Lyons, Vienne, Paris, Neri, Grand Drevant, Bruieres, Valonges, Besançon, Metz, Perigeaux, Nice, Doue sur l'Ilgers in Poictou. In Spain, at Hispalis near Seville, Tarragona, Saguntum, and many other places.

At Smyrna is one of stone, in good preservation; also at Sardis, the capital of Lydia, Jerusalem, Argos, and Melos; Udena, near Tunis, is another, very perfect and beautiful, and Constantinum, Istria, Tergeste, Ægeda, Parentium, and Pola, each had their amphitheatre. Those of Nismes, Udena, the Coliseum, and Verona, are the most perfect that remain.

Amphitheatre of Vespasian, called *Coliseum*, finished by the Emperor Titus about the 79th year of the Christian era, is of an oval form, its diameters being 620 and 513 feet, measured to the face of the outer wall, from which the semi-columns project. The entire height of the building is 157 feet, divided by four orders of architecture; the upper has pilasters, the others half columns. Its entire area may be estimated at 249,804 superficial feet, or nearly six acres; the cubical contents of the mass and void at nearly 40,000,000 of cube feet. The arena, 287 feet in length, and 180 feet 3 inches in width, is an area about one-

sixth of the whole, or a little less than an English acre. It has been estimated that 500,000 tons of material were used in the construction of this amphitheatre. Each of the three lower stories has 80 arches; and medals show that the two upper ranges were decorated with statues. In the year 1813 the arena was excavated, when substantial walls, finely worked with pepperino stone, were discovered, that had supported the timber floor: they were formed into corridors and receptacles for wild animals collected for the shows.

The podium, surrounding the arena, was of a sufficient height to protect the spectators from attack of the animals: from thence to the summit were steps or seats of marble, which were 17 inches in height, and about a foot or 13 inches in width.

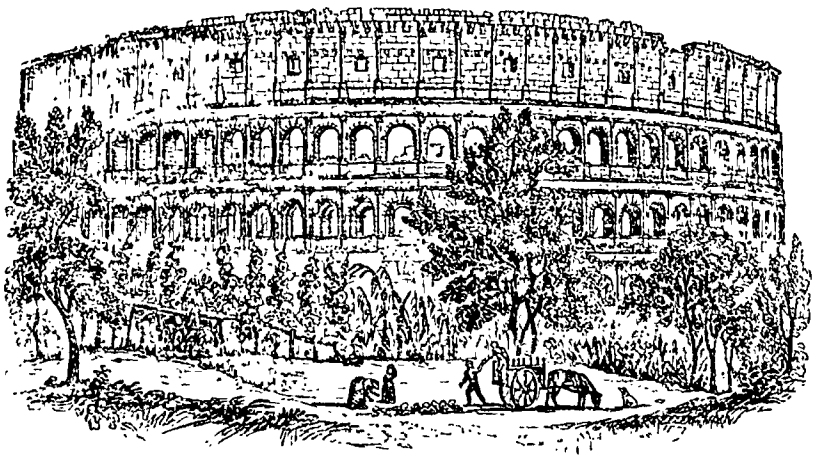


Fig. 125. COLISEUM.

Five corridors of communication extended round the building; the two outer formed of open arches, which, as well as the piers, were constructed of travertine stone; the whole paved with thick travertine slabs, extending nearly 6 feet beyond the face of the outer wall. From the inner corridor arose two varieties of staircases, which conducted to the Ionic range: from the third corridor other staircases also conducted to the same level.

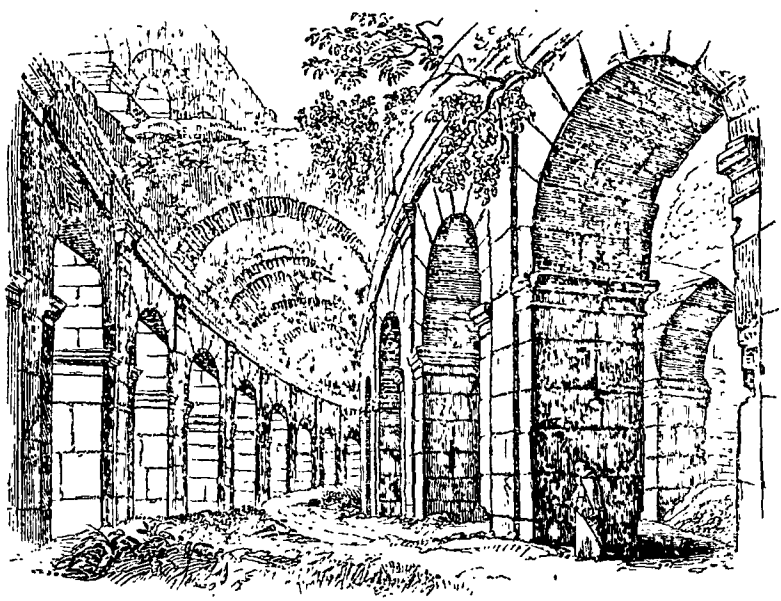


Fig. 126. COLISEUM.

The division walls, which radiate from the third to the two outer corridors, have each four distinct piers of travertine stone, with spaces between filled with pepperino, the horizontal joints of which do not always correspond. The walls between the third and fourth corridors are faced with tiles in regular courses; the outer pier is alone of travertine, and forms a break.

The vault of the fourth corridor is entirely destroyed; the marble pavement remains, 5 inches thick, which seems to indicate that this was the approach to the podium, where the emperor and persons of rank were seated.

The rain which fell upon the several seats and the arena, and the water which flowed through urinals, and other arrangements made for the convenience of the multitude assembled within the walls, drained into wide and spacious sewers, which were conducted into the Cloaca Maxima. A large drain in the second corridor, 30 inches wide, received the water, brought down by perpendicular pipes worked in the solid masonry, or placed in indents, lined with tile. The drain of the third corridor, 17 inches wide, and 3 feet in depth, is lined carefully with tile and coated with a fine cement. On the outer side of the third corridor, a similar drain, with a fall towards the last described, caught all the water brought by the several branches from the arena.

The total area of this building has been stated to be about 249,840 feet; that of the arena, within the present podium wall, 40,575 superficial feet: consequently, the area occupied by the walls, piers, and corridors, will be the difference of these two quantities, which will be found to be 209,229 feet.

The true points of support are the following:—

80 outer piers, the area of which is	= 5,360 ft.
80 second piers, the area of which is	= 3,600
80 third piers, the area of which is	= 2,640
80 division walls to the third corridor	= 14,400
80 division walls to the fourth corridor	= 6,640
80 portions of the arena wall	= 9,200
	41,840

The points of support are, in area, 41,840 feet, about one-fifth of the mass, or one-sixth of the total area of the entire amphitheatre, which is about the proportions that exist between the total area and the points of support in St. Paul's, at London.

The 80 piers and division walls are not set out very exactly; they diminish in thickness as they radiate to the four centres of the ellipsis.

Exterior elevation, consists of 4 stories of different orders formed of travertine stone. The height of the lower, or Doric, including its attic above, is 40 feet 7 inches, which is level with the pavement of the first story.

The height of the Ionic order and its attic, level with the pavement of the second story, is 38 feet 7 inches.

The height of the Corinthian order and its attic, nearly corresponding in level with the pavement of the upper internal corridor, is 40 feet.

The height of the upper wall, with the pilasters and its entablature, is 38 feet 4 inches.

The total height of the present wall is, as stated, 157 feet 6 inches.

The openings of the arches average 14 feet 4 inches, which is the height up to the top of the impost moulding, on which the semicircular arches rest.

The upper order, above the three ranges of corridors, has its cornice perforated for the insertion of wooden masts, which supported the velarium; the total number were 240. The interior portion of this wall is faced with tiles in regular courses, behind which, placed in indents, and well bedded in cement, are circular earthen pipes, that conveyed the water from the wooden platform above to the drains below.

The piers are all formed of travertine stone in large blocks, many extending the whole depth of the pier, which is 8 feet 8 inches; the joints are well worked, and each stone securely cramped with metal, all of which, that could be removed, have been taken away. Each of the arches is formed of 11 voussoirs; the key-stone, as well as many of the others, extending through the whole depth of the wall. These voussoirs have on their sides mortices and tenons, which prevent their sliding, also iron cramps.

The Sections through the building exhibit its construction most perfectly. The back face of the outer piers and wall above is perpendicular, the outer face retreating on each story. At the top it is 6 feet 9 inches in thickness; at the Corinthian story, 6 feet 3; at the Ionic, 8 feet 5; and at the lower, 8 feet 9 inches.

The width of the outer corridor in the clear is 17 feet, that of the second 14 feet 6 inches, that of the third 14 feet 6 also, and the fourth corridor 11 feet 6 inches.

The main piers are all of travertine stone; the division walls between the third and fourth corridor, and those between the second and third on the first story, are faced with tiles filled in with rubble work. The division walls between the second and third corridors have four piers in

travertine, with the three spaces between filled in with pepperino, or a softer stone. The vaults over the corridors and staircases are turned with rubble, very roughly executed, the goodness of the mortar or cement constituting its strength. After the piers and division walls were carried up to their proper heights, boarded centres were placed, on which the rubble was laid and grouted together: many of the divisions still show the marks of the planks used, which were laid longitudinally. The vaults being turned over the entire space, comprised within 116 feet, or from the face of the present podium to the back of the wall, which shut out the corridors on the level with the Corinthian order of columns, and floated to a uniform inclination, received the marble seats, which were 3 feet 5 inches in width, placed one upon the other, so as to allow a seat of 2 feet 5 inches wide.

Some idea may be formed of the number of persons it contained, by allowing a space of 15 inches to each, or an area of 3 superficial feet: as the total area of seats which covered the interior was 209,229 feet, the number that might be accommodated was 70,000, without comprising those seated on the podium, now destroyed.

The staircases conducting to the several vomitories were admirably constructed, and built of stone.*

From the second corridor was the ascent to that immediately over it, by twenty flights of double staircases, easy in their rise, each having three spacious landings. The same corridor was arrived at by sixteen other staircases, which commenced in the third corridor: these had an easy rise, and a wide landing in the middle of the flight. From the last named corridor, sixteen other staircases led to the seats over the fourth corridor; there being fifty-two staircases from the ground floor to the corridors and vomitories above.

Sixteen flights of twenty-eight steps conducted from the third corridor of the Ionic order to the first mezzonine obtained under the vault of the second corridor of this story: sixteen other staircases led from hence to the corridors of the Corinthian order.

From the second corridor of the Ionic range were sixteen staircases, which led to the third range of vomitories.

Twenty-four flights passed through the upper mezzonine, and eighteen conducted to the top of the platform, on which the arrangements were made for the adjustment of the vela. The fourth corridor, on the ground floor, was paved with marble, 5 inches in thickness; the others with travertine in large slabs; and great attention was paid to the carrying off the waters, and effectually draining the entire building.

In the year 1818 the writer was occupied for many months in measuring this splendid edifice; and to the numerous drawings published in the "Roman Antiquities," he must refer the reader for a more detailed account of its arrangement and distribution, being able to vouch for the dimensions there given.

The Amphitheatre at Nismes, from some fragments of an inscription found, is supposed to have been built between the years 77 and 82 of the Christian era.

Its plan is that of an ellipsis, the longer axis of which, measured on the external facing at the pedestals of the eastern and western entrance, is 437 feet 6 inches; and the short axis, measured also at the faces of the pedestals, 332 feet 6 inches. The interior, measured within the podium, the longer diameter is 226 feet 8 inches, and the shorter diameter 125 feet 9 inches; from thence it results the thickness or depth of the construction from east to west is 103 feet 4 inches, and from north to south 103 feet, which difference is accounted for by the projection of the pedestals at the east and west ends.

The four entrances, answering to the four cardinal points, were the only communications with the arena. It appears by the dimensions, that those to the east and west were destined for the use of the spectators, the others being reserved for the service of the arena. The east and west entrances were 13 feet 4 inches wide, and those north and south only 3 feet 6 inches; the former led to the arena by an inclined plane, the latter by steps.

All the division walls are set out at equal distances on the out as well as on the inside. The exterior circumference, and interior, around the podium, were divided into sixty equal parts, setting off from the two axes, on which were the centres of all the stairs, porticoes, and rampant vaults. Between the centre of each of these sixty divisions a line was traced, on which the walls were set out. The divisions and their corresponding parts are of a uniform width, which must have occasioned great difficulty in the execution, although affording facility for the internal distributions.

The plinth of the exterior porticoes is elevated 7 feet 9 inches above that of the wall of the podium.

The total height of the amphitheatre is 70 feet; the lower order, 33 feet; the upper, 29 feet 8 inches; and the attic, 6 feet 4 inches.

The foundations of the external pilasters are placed 8 feet 10 inches below the plinth, and the wall of the podium rests on a simple plinth a foot in height. If to this is added 7 feet 9 inches, the height of the external plinth above the podium, we have a height of 8 feet 10 inches, which is the depth of the external foundations below the plinths. It is evident, therefore, that all the foundations were made on a level. After the plan was traced, the ground was taken out to a depth of three feet, and filled with concrete. Sixty arcades

formed the elliptical boundary of the amphitheatre. Their openings, with the exception of those to the north, the east, and west, were all 12 feet 5 inches; the other three 13 feet 2 inches. The width of the external piers, 8 feet, the pilaster of which occupies 3 feet, and the faces on each side 2 feet 6 inches. The exterior has two orders surmounted by an attic; the lowest without bases. The pilasters are in height 26 feet 3 inches, from the zocle to the top of the capital.

The second story, comprising pedestal, column, and entablature, is in height 29 feet 6 inches; the pedestal, 3 feet 6 inches; the column, 20 feet 6 inches; and entablature, 5 feet 6 inches. The column projects two-thirds of its diameter, and at the base is 2 feet 7 inches in diameter.

The height of the attic is 6 feet, and its face is fair with that of the column below: two strong stone corbels, pierced with circular holes, between the pedestals, supported the masts that received the *cords* of the vela or covering. There are thirty-five ranges of steps or seats, besides those which divided the whole into precincts. There are four precincts, each having its separate staircases and vomitories. The lowest precinct, nearest the arena, reserved for the principal inhabitants, was formed to receive four seats only, each 1 foot 8 inches in height, and 2 feet 7 inches in width; to protect the lowest of these seats, towards the arena, a podium or wall of one stone, 6 feet 6 inches in height, and 3 feet 3 inches, was built up.

The second precinct was separated from the one mentioned by a wall 3 feet 4 inches in height; this consisted of eleven seats, and forty-eight vomitories, sixteen of which had their entrance from the interior gallery of the ground floor, and thirty-two from the gallery of the entresol.

The third precinct, with ten rows of seats, was separated from the second by a step, in a similar manner to the others. These were approached by thirty vomitories out of the gallery of the first story.

The fourth or upper precinct had ten seats, the last of which rested on the attic wall. They were arrived at by thirty vomitories whose entrances corresponded with the gallery of the second story.

The Staircases were numerous: twenty-eight conducted from the external gallery of the ground floor to the gallery of the entresol; a like number from thence to the first story; thirty-two led from the gallery of the ground floor to the vomitories of the first and second precinct. A similar number from the gallery of the entresol to the vomitories of the second precinct. Thirty others from the gallery of the first story communicated, first, to the thirty vomitories of the third precinct, and then to the double staircases, which led to the second story, where the thirty vomitories of the fourth precinct were placed. These last were contrived in the head of the vault of the gallery of the first story, and received their light from small openings pierced on each side of the capitals of the columns on the lower story.

The five several galleries held the spectators during the intervals of the exhibition or violent storms: in a few moments the whole amphitheatre might, by means of the 130 vomitories, have been cleared; and in a small space of time the spectators could, without confusion, have again taken their seats.

The amphitheatre has been calculated to contain 23,362 spectators, each person occupying only fifteen inches superficial. The total length of the steps or seats is 30,660 feet; but some allowance must be made for the loss by vomitories, &c.

For carrying off the superfluous waters, which might collect in such vast edifices, the most ingenious contrivances were thought of and introduced at the very commencement of the work, and so admirably arranged as not to weaken the walls or piers which contain them. Many of these conduits served the double purpose of urinals, and numerous are the precautions taken to prevent their becoming offensive, and to provide for their proper and thorough cleansing. The Roman engineers have taught constructors a lesson which has not been sufficiently appreciated nor imitated in the public buildings of modern times, where vast numbers remain for many successive hours. By a careful study of the drainage of an amphitheatre, we shall be enabled to understand the attention paid to the setting out of the sewers of a city. The Coliseum and many large buildings retain all their pipes and drains, showing us how admirably this object was carried out; modern practice has not yet devised a more perfect or effectual method.

Fifty-six drains, constructed within the thickness of the walls which supported the staircases of the ground floor, served for the rain water to pass off, and for the convenience of the spectators placed in the third and fourth precincts. Their upper opening was on the landing of the entresol, above the gallery of the first story; half the openings of these drains were placed opposite the stairs which led to the gallery above, or that of the second story; the other half was enclosed, and formed into a recess, which concealed them from the view of those passing by. We presume the first were for the convenience of the men, and the others for the women.

These drains were formed of cylindrical pipes 12 inches in diameter, hollowed out of the middle of large masses of freestone 20 inches in height, the beds of which were

alternately placed square and jutting out, the better to unite them with the adjoining masonry; almost all the latter formed the thickness of the walls, within which were the pipes. The upper bed of each stone, 6 inches round the opening, is cut in the form of an inverted cone, as is the lower bed, the other part of the bed being level: all these beds or joints, being placed one within the other, formed an ascending joint 2 inches in height, and prevented any filtration of water into the body of the masonry. These drains carried off all the urine and rain water.

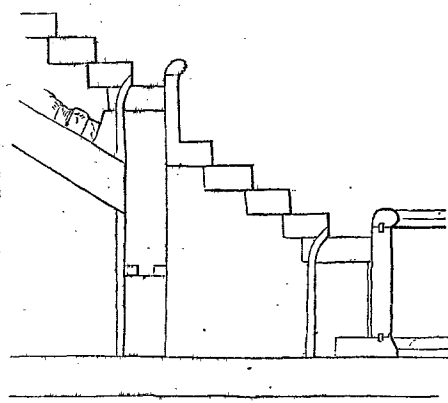


Fig. 127. DRAINS.

A hole, 2 inches in diameter, sunk in the middle of a stone, slightly dished, formed the entrance of all the drains of the lower stories, from which it is concluded they were used for a similar purpose. Besides the upper openings of these fifty-six drains, in the landings above the gallery of the first story, there was a similar number, and also in the passages of communication with the two corridors of the ground floor; they are at 1 foot 9 inches above the ground, and might serve to cleanse the issue of the *gargouille* which poured forth the waters into the outer aqueduct.

The drains communicated by a gutter or channel of freestone to a well or cesspool, 2 feet 4 inches in diameter, under the stairs of the ground floor, in the mass of masonry which supported them; the bottom of this well communicated with a small aqueduct, 13 inches wide by 18 high, having a considerable fall, the lining formed with the greatest care in moellon and mortar: the base and covering being executed with large stones. This aqueduct conducted diagonally to the middle of the under side of the stairs, where it united with that of the corresponding drain; at this point the two emptied themselves into one of 18 inches in width by 22 in height, the issue of which was made under the pavement of the exterior corridor, in the centre of the portico, which carried the great stairs of the lower floor, and at 3 feet below the pavement of this same gallery: this issue was formed by a large stone, so placed against the covering of the aqueduct, that at the two sides a passage was left for the water. The external gallery of the ground floor, under which the drains discharged themselves, and all the passages which communicated from the two galleries, were entirely filled up with chippings of large pieces of freestone, from the level of the foundations, to within 6 inches below the plinths. This latter height was occupied by an inclined floor of cement, serving as a pavement to the two corridors as well as the other passages. The waters easily filtered through thin chippings of freestone, and the humidity and disagreeable odour was prevented from affecting the galleries, by the interposition of the bed of cement which covered these fragments. The water and urine ran off by infiltration into the drains, which could only serve for the purposes indicated, particularly as their entrances, still preserved in the vomitories of the first and second precincts, are only an inch and a quarter in diameter.

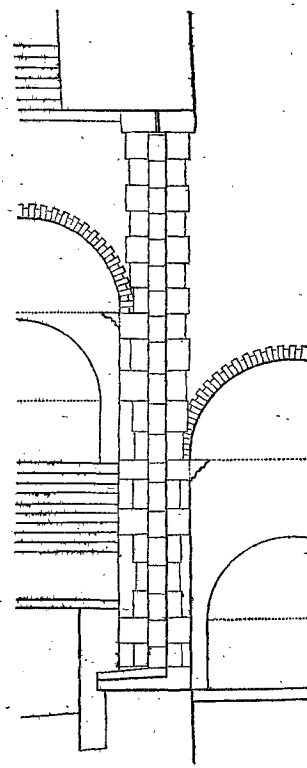


Fig. 128. UPRIGHT DRAINS.

Sixty-four other drains, found in the passages of the vomitories of the first and second precinct, corresponding with the interior gallery of the ground floor, were for the same purpose. A drain placed on each side of the set-off of these passages, with a hole 2 inches in diameter, formed in freestone, slightly dished out,

received the rain water and conducted it outside. A like number of drains is also contrived above the set-off of the staircases which led to the entresol and the first story. The gargouilles, placed over each other, follow the direction of the stairs, then cross the walls which support them, pass behind the stone jambs of the porticoes and galleries of the entresols, then return under the landings and the stairs of the ground floor, and are at last collected in the receptacle connected with the great drains.

The draining so large a building occupied great consideration; the forethought displayed in these arrangements evinces great ingenuity and simplicity. The surface of the arena was rather higher in the middle, and sloped gradually and uniformly towards the podium. This form had the double advantage of dividing the rain water, and preventing the injury which a collection in the centre would have occasioned, and of placing the spectacle on a plane, which by its form brought it nearer to the spectators. The convexity of the arena required the oval aqueduct to be placed at a little distance from the walls of the podium, to receive and conduct away all the waters. It was consequently 7 feet 6 inches distant from the wall of the podium, 3 feet 6 inches in width by 4 feet 9 inches in depth. The walls are of moellon laid in cement. Small channels very close to each other are cut from the base of the podium, to conduct the water to the aqueduct. This aqueduct was covered with stone 8 inches thick, which rested on a bed of freestone 6 inches high, forming a slight projection on the internal face; the upper part is an inch and a half below the base of the podium, by which means the sand that covered the arena extended also over the flags which covered the aqueduct sufficiently to prevent any injury occurring to the gladiators when they fell. These flags rest 8 inches at each end on the bed of freestone which crowns the walls; they are also attached by a dovetail half an inch in depth. The inclination or fall given to the bottom of the aqueduct is regular throughout.

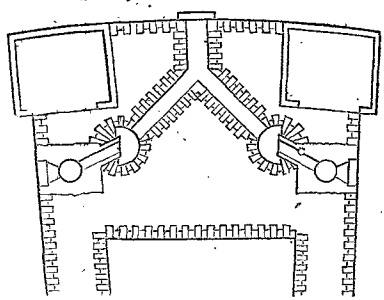


Fig. 129. PLAN OF DRAIN.

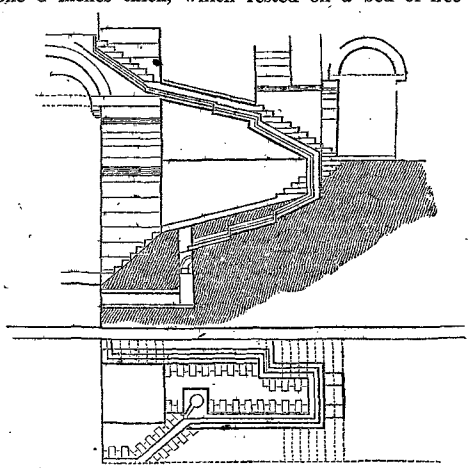


Fig. 130. SECTION OF PIPES AND PLAN.

The thickness of its side walls is 18 inches. The outer part is backed against the concrete in which the aqueduct is entirely surrounded. The wall on the side of the podium is open opposite the two east and west gates to receive the water of a second inner aqueduct, which will be hereafter described. All the waters of the arena flowed into the inner aqueduct, and it remains to show in what manner that which fell on the seats, in the vomitories and in the galleries was carried through the opening of the great outer porticoes.

All the seats had an inclination of the sixteenth of an inch forwards, which facilitated the flowing of the water from the upper to the lower step, and from one to the other. The first precinct was defended in front by a parapet which rose 21 inches above the step, so that the rain water which fell on the four rows of seats and the step of the first precinct, being stopped by the parapet, could not flow into the arena. The Romans might easily have pierced this parapet at the level of the step, and discharged the water of this precinct into the arena; but such an arrangement would have injured the ornamental effect of the podium.

The water of the first precinct was therefore made to pass off by an opening at the base of the first seat on the level of the step, to which, for this purpose, a slight fall was made towards the seat. Circular openings cut in a conical form, 4 inches in diameter, allowed the passage of the water from the first four rows of seats, and carried it behind the wall of the podium, by a small conduit made in the stone step; afterwards it was received at the foot of this wall into a small channel two feet wide, which, traversing the lower part

of the first precinct, and the foundation of the parapet wall of the second, arrived at the great circular inner aqueduct. Twelve of these discharges sufficed for carrying off the water of the first precinct, which was only composed of four rows of seats.

The second being protected like the first by a parapet, the same method for discharging the water as those already explained was adopted, this second precinct receiving also the water from the cornice of the attic. Twenty-four discharges at the level of the step of this precinct carried the water behind the wall of the second podium, and through the middle of the vault which covered the chamber through which the great circular aqueduct passes. At the summit of this vault, against the wall of the second podium, a large stone pierced with a hole four inches in diameter received the collected waters. These holes have led some to presume that they received the posts intended to support the tent which covered the amphitheatre. Their nearly horizontal position, and their conical opening, at once show their destination.

The water which fell on the arena and seats of the amphitheatre was conducted into two circular aqueducts, that of the arena, and that of the interior. The latter, which followed the contour of the building, is 30 inches wide; its base, on the same general level as the foundation, is formed of two walls, faced with dressed stone 6 feet 6 inches high, having its course through the chambers which receive the water of the first and second precinct: it is arched in the thickness of each wall, under the issues of the vomitories of the first and second precinct, corresponding to the inner gallery of the ground floor, and under the passages of the north and south doors. It also communicates with, and empties itself into, the aqueduct of the arena, under the two great passages of the east and west doors, by two square openings, 30 inches wide by 20 inches high. The aqueduct under the great east and west passages is covered with large landings resting on walls built on each side.

The inner aqueduct received all the water which fell through the openings of the thirty-two vomitories of the first and second precinct, the entrances of which corresponded to the inner gallery of the ground floor. This water, which during storms is abundant, was stopped on the landing of the passage of each vomitory by a step whose tread was hollowed out to a depth of half an inch. A hole two inches in diameter, opened at each extremity of this step in the recesses of the vomitories, served as a urinal, as well as received the rain water, and then passed into the aqueduct immediately below. By this means the water falling through the openings of the vomitories could never come into the inner gallery on the ground floor.

The rain water driven by the wind into the outer gallery of the ground floor through the openings of the sixty arches of the façade would soon have inundated this gallery if means had not been provided for getting rid of it by a rapid and successive discharge. The paving of the outer gallery, and that of all the passages of communication, had a fall of 6 inches towards the inner gallery, so that the rain which the wind blew into the outer gallery ran into the second. At the foot of the piers which divide the passages of the vomitories, it met with a discharge into a small aqueduct, which conducted it into the great inner circular aqueduct: the smaller opening into the larger by a hole 3 feet high, 18 inches wide, and 16 inches above the base of the great aqueduct. A similar discharge remains in the middle and at the foot of the first step of the great staircases, which admits under the paving of the outer gallery, a part of the waters of this same gallery.

The inner circular aqueduct received all the water of the seats and steps from the attic to the podium, that of the thirty-two vomitories whose entrances corresponded to the inner gallery of the ground floor, and that which the wind carried into the outer gallery through the openings of the entrance porticoes: all this water united formed a considerable quantity during storms; but it was so divided, and so well directed, that it was impossible any stoppage could take place, or that it could ever inundate the galleries and passages, much less injure the solidity of the masonry. By such means the Roman engineers, who were masters in the art of construction, effectually drained the upper galleries and vomitories.

The inconvenience arising from the chance of the water penetrating into the passages and galleries through the openings of the thirty-two vomitories of the first and second precincts, was obviated at all the upper stages to which the issues of the other vomitories correspond, the same pains being taken to get rid of it quickly. The gallery of the half story of the first floor could easily be inundated by the openings of the thirty-two upper vomitories of the second precinct, to which this mezzonine gallery was solely destined, but the first step of the stairs of each vomitory was slightly hollowed and pierced in the middle with a vertical hole, an inch in diameter. Below this step and hole is a stone cut in the form of a cistern 5 inches deep, 12 long, and 8 wide. At the end of this cistern is a gargouille 4 inches wide, closed at one extremity, and pierced with a perpendicular hole. The pavement of the half-story gallery, which throughout is tooled, is formed opposite each vomitory by a stone similar in all respects to the tread of the first step of the staircase of the vomitory: this is slightly hollowed and pierced with an aperture which corresponds with a small hole made through the vault, which carries the inclined winder and the second revolution of the great staircase of the ground floor. The water which fell in the passages of the vomitories, on

arriving at the first step above the pavement of the gallery of the half-story, was received into the perpendicular hole with which this first step is pierced, then fell into the cistern placed below, ran down the gargouille, at the extremity of which it fell into the chambers under the great staircase, where it was quickly absorbed. If the abundance of water was such that the first step could not receive it, the excess fell on the stone placed below on a level with the pavement of the gallery, where it followed the same course as the rest, and ran under the same vault by a similar contrivance, so that it was impossible any could come into the half-story gallery.

The water which the wind drove into the first-floor gallery, through the openings of the porticoes, fell on the first step, by which it descended to the half-story gallery. There it was received into the hollows of the first step, at the extremity of which were two holes an inch in diameter, below which were stone gutters communicating with discharges made on each side of the recesses of this staircase below the winders just mentioned. The water then followed the course indicated above: a double advantage was thus obtained, that of cleansing the urinals and getting rid of the water, which, without this precaution, would have inundated the inner gallery.

The great discharges of the second flight of steps, fifty-six in number, received the water of the vomitories of the third and fourth precinct.

The construction of the great outer aqueduct, which brought the water from the fountain of Nismes, is next to be considered.

It was discovered when excavating in the middle of the outer gallery of the ground floor, opposite the north gate, where an aqueduct was supposed to exist under this gallery and throughout its circular development. This great aqueduct has a breadth of 32 inches, and a height of 6 feet from the bottom to the under side of the key-stone which covers it. Like all the others, it was filled with earth and mud up to the top: on the north side it was found perfectly preserved, built of tooled stone, as was the semicircular arch which covers it. This vault has been replaced by landings of freestone, where it crosses the north passage from the door of the present guard-house to the circular aqueduct of the arena. It traverses the arena to the centre of the ellipsis, then deviates to the south-west, leaving the building at the sixth portico east of the south door. Its construction, precisely the same as that on the north side, is covered with landings. The excavation was continued from where it issues from the amphitheatre, for a length of 40 feet, at which distance it was broken and could not be further traced.

Two manholes for descending into this aqueduct existed in the outer gallery on the ground floor, one at its entrance at the north gate, the other at its issue through the sixth portico west of the south gate. These manholes are perfectly preserved: they are 2 feet square, covered with a landing: below the pavement a square hole 30 inches wide, by 16 inches high, is cut, 3 feet 6 inches above the bottom, on each side of the aqueduct, in the middle of the outer gallery on the ground floor, to allow the water which filtered through the pavement to run into the great aqueduct.

Three quarries were worked by the Romans to obtain the stone requisite for the external works of this amphitheatre: the greater part of the seats, and facing of the podium of the first and second precinct, and some portion of the interior arcades, were of stone, brought from the quarries of Baruthel; some steps and the worked moellon came from Roquemaillère. Nearly the whole of the arcades of the lower story, the entresol, the first and second story, are executed in the stone from the quarries of the Pont du Gard. They are all calcareous, and of a grain more or less fine. That from the quarries of Baruthel is compact, firm and fine; its weight about 515 lbs. per cubic foot: when employed as it is found in the bed, it is an excellent stone, in many instances where this precaution has been omitted the courses are entirely decomposed.

The stone from Roquemaillère is stronger and harder, and weighs about 460 lbs. per cubic foot; it is of an excellent quality, and has undergone little change.

That brought from the quarries of the Pont du Gard is a coarse grit, and stands well when used internally: being porous, when subject to exposure or rain, it is greatly injured: a cubic foot weighs about 333 lbs. The difficulties arising from the oblique direction of the whole of the constructions, externally and internally, are admirably overcome. The vaults of all the stories are executed with great precision, as are those of the corridors; but the same care has not been taken in the construction of the arches of the exterior, which are oblique on their plan and elevation. The Romans in this example of oblique work had not quite arrived at perfection, as they have not been sufficiently attentive to the true setting out of each stone. All the freestone is laid in cement, and the bed cut with the utmost precision; a hole in the centre of gravity of each stone indicates that it was lifted by the aid of the Lewis; and it appears, by the nicety of the workmanship, that the upper stone, previous to being bedded, was suspended by the Lewis, and, water being thrown over the under bed, was then gradually lowered: all the rough particles that might remain between were brought down by friction; and when the stones easily worked against each other, the upper was definitively fixed. By no other means can we account

for the excellence of the joint: the small particles of the stone rubbed down, mixing with the water thrown on the lower, formed a cement, filling up the void between them.

All the workmanship of the amphitheatre is of a colossal kind: many of the stones contain from 25 to 35 feet cube; their beds are from 12 to 15 feet superficial, which adds much to the difficulty of the execution.

The facings were not so carefully attended to as the joints and beds, it evidently being intended they should be dressed after the completion of the work, which was the common practice with the Romans. In all their constructions they took the precaution of uniting the stones together by two oak wedges cut in a dovetailed form, placed over each joint, sunk in the stone to a depth of $2\frac{1}{2}$ inches; these were about 4 inches in length, and all that remains, upon a careful examination, is a ligneous dust, the wedges having perished long ago.

The cutting of the moellon, employed in the walls and the vaults, is admirable; the courses are from 5 to 9 inches in height, and the stones are from 8 to 10 inches in length. Their faces are coarse, and the joints and beds so cut that the stones may be united closely at the edges with an exactness almost incredible. The edges or arrises of the moellon are as sharp as if of freestone: the same nicety of execution runs throughout the vaults where moellon was employed, and the voussoirs, which are from 15 to 20 inches in height, and from 7 to 9 inches in width, are cut with the greatest care, relatively to their conical and rampant projection. All the moellon was bedded in cement; but little is to be seen, on account of the extreme fineness of the joint. The filling up of the masses, spandrels, &c. was with rubble stones of all shapes, run in a coarse cement, which has become as hard as the stone itself; this was composed of equal parts of quicklime, gravelly sand, broken tiles and bricks. Wherever iron is used, it is run with lead; the iron cramps for placing the stones of the podium are so cased.

The velarium or covering. — For several ages, the spectators in the amphitheatres were uncovered, as we find the ancient historians often allude to the necessity of quitting their seats, on account of the rain which fell. And St. Chrysostom reproves the people (Hom. 4. c. 16.) for having stood bare-headed with the sun scorching them in the theatre. We also learn, from many inscriptions which are in the collection made by Gruters, that the theatres were provided with covered porticoes, to shelter the people assembled. Pliny and Valerius Maximus both state that Quintus Catulus was the first who contrived a vela, or shade, for the people assembled in the theatre; and the first of these authors gives the name of Valerius of Ostia as the engineer employed to execute the work. Lentulus Spinter (Pliny, l. 19. c. 1.) formed the vela first of linen cloth, and Dio (lib. 43.) tells us that Cæsar introduced one of silk, to keep off the heat of the sun's rays at the amphitheatre, constructed of wood. Silk, in the time of the emperor Aurelian, was in value equal to its weight of gold, and therefore must have been a great luxury. The emperor Nero spread over the theatre a vela bespangled with golden stars, on which was represented Phæton driving the chariot of the sun, the material of which has been supposed was wool, as sometimes, in its description, the word Apuliæ is made use of, and dyed wools were brought from that country.

Lampridius (in Com. a Militibus, Classiariis) informs us that the management of the vela was left entirely to sailors, as they were more expert in going aloft amidst ropes, and understood the tackle which regulated the spreading of it better than others. There can be no doubt that it required considerable dexterity on the part of the engineer to keep steady an awning containing 113,345 superficial feet, which would be required for the amphitheatre at Nismes, and for the magnificent Coliseum nearly 250,000 superficial feet, or more than double; the weight of which, at only one pound per foot, comprising the ropes and tackle, would amount to 112 tons or thereabouts. So vast a weight disposed and upheld by tension only creates our wonder and admiration.

At the level of the attic story are 120 projecting consoles, each having a circular hole about 10 inches in diameter, corresponding with a circular mortice of the same size, and 6 inches in depth, made in the projection of the cornice of the second order. The upper opening of the hole in each console has externally a groove 2 inches in height, destined for an iron collar, to which was attached a tie, which secured it to the wall of the attic at the level of the top of the console: the holes which contained these have some portions of the iron run with lead remaining.

The hole of each console received a round mast, which, passing through it, rested in a hole sunk in the cornice below, the iron collar preventing it from acting against the sides of the console and fracturing it. The masts alone would not be sufficient to support the weight of the vela, extending over an elliptical area, the axis of which, in one direction, was 436 feet, and in the other, 331. To aid in the support other posts were introduced through mortices about 10 inches in length, placed opposite each console, at the projecting part of the moulding which crowns the interior of the attic; on each side, 4 or 5 inches from the edge of the attic, are holes still containing the lead which secured the iron ties that held

these latter posts in their places. Under the mortice holes are others, 8 inches square, and 2 feet in depth, made in the upper step of the attic to receive the second posts. The two posts were afterwards securely braced.

Over the centre of the arena was an oval covering, permanently fixed, which in the Coliseum was ornamented with an immense golden eagle. Round the edge of this oval covering was attached a large cable. 120 pair of cords, of equal length, stretched from the masts on the exterior to this cable, were worked by pulleys; thus forming as many compartments. Each pair of cords was furnished with rings, to which the covering was attached, so that it could be drawn backwards and forwards at pleasure. The whole of these were called the vela or velaria, and each single compartment velarium. The distance between the ropes on which the velarium ran was greater towards the attic than at the centre; consequently, to make the velarium run freely on its rings, it was necessary that it should be of an equal width throughout: when spread, towards the attic it was stretched, whilst towards the centre it sagged, and formed as it were a fold. To prevent the sun passing through the opening thus made by the sagging, an internal hanging was attached around the fixed permanent oval.

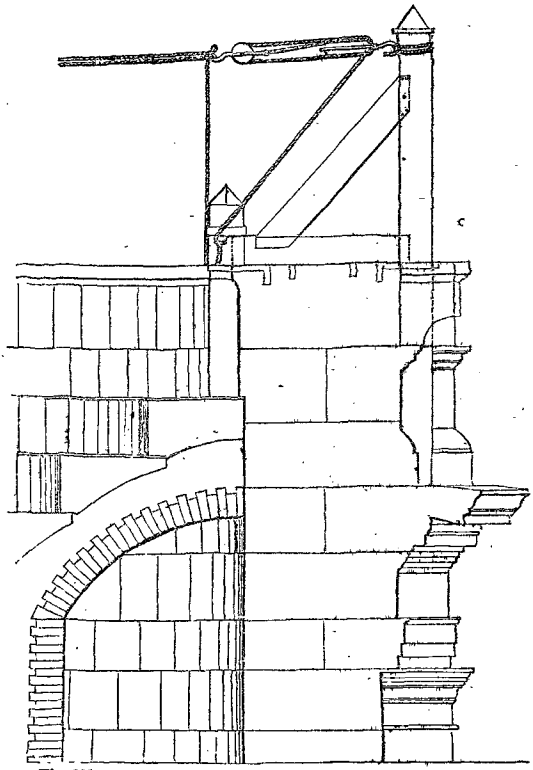


Fig. 131. POSTS OF THE VELA.

The weight of the vela was sufficient to make it drop considerably in the middle, whatever caution was used in tightening the ropes: another inconvenience to be guarded against was, the action of the wind upon it. At the back of the podium wall are remaining many holes, which contained iron rings, run with lead, supposed to have been used to secure the blocks, through which passed perpendicular ropes, which being kept tight would obviate this inconvenience.

Amphitheatre at Verona. The longest axis of the ellipsis is 495 feet; the shortest, 396 feet. That of the arena within the podium is 240 feet, and the shortest diameter 141 feet. The total circumference of the exterior wall is 1419 feet; the height which remains is about 88 feet, though originally it is said to have been upwards of 130 feet.

There are forty-five ranges of seats or steps remaining, exclusive of the first, and it was calculated that 22,000 persons could have been accommodated within the walls. The outer wall is nearly demolished: it had three orders, and an attic built of coloured and white marble: the three lower had arches separated by pilasters. The mouldings of the upper story, as well as the capitals and cornices of the other two, are of white marble. All the seats are of red marble. The stones used in the construction are of large dimensions, and pass through the entire thickness of the wall; but the courses vary in height. On each story were seventy-two arches, and each had its number engraved upon it. The staircases are well contrived, and in some degree resemble those of the Coliseum. There were in all sixty-six entries, including the two great gates: six led into the arena; twelve straight passages conducted to the seats over the podium, and each had five steps.

The wedges or cunei above were entered from the outer portico, by eight single staircases and four double ones. The fourth round had sixteen vomitories or openings, and was ascended by eight smaller staircases.

There were sixteen long rooms of considerable height, and eight smaller under the stairs. Twenty-eight dens or caves and other rooms were contrived in various parts for the animals and those who attended.

The Amphitheatre at Pola in Istria, situated out of the town, is not in a very perfect state. The longest diameter from north to south is 436 feet 6 inches; the other, 346 feet 2 inches: its height, 97 feet. The exterior is rusticated, and has two orders of pilasters, the lower placed on pedestals, above which is an attic. Around the ellipsis are seventy-two arches, the extreme being both higher and wider than the others. It is built of stone from the neighbourhood, in appearance resembling marble, and based upon the solid rock. The architect who constructed this edifice placed it on the side of a hill, to economise the masonry.

This amphitheatre was probably erected by Diocletian, or by Maximin: the interior is quite destroyed, not any of the division walls or seats remaining, a wide area extending to the outer wall.

Amphitheatre at El Jemm in Africa is one of the most perfect, vast, and beautiful remains of this kind of structure that exists. It is situated at a short distance from the shores of the Mediterranean Sea, in the beylek of Tunis, from which place it is about eighty miles distant to the south, and not far from the shore of the ancient Syrtis Minor.

It is probably the ancient Tysdrus or Thysdrus, five miles south-east from Elalia, and thirty-three miles from Leptiminus. This amphitheatre has four stories, each of the three lower adorned with sixty-four arches and columns: the upper is a pilastrade, with a square window in every third interpilaster.

With the exception of one breach, the circuit of the walls is entire; the interior is less perfect. The inclined plane on which the seats rested remains, as do all the galleries and their vomitories. Beneath the arena are deep pits of hewn stone. The length of the building from east to west is 429 feet, the breadth 368 feet.

The arena measures 238 feet by 182 feet. The floor of the first arcade is 33 feet from the level of the exterior pavement, and the height of the outer wall was probably 100 feet.

The elder Gordian was proclaimed emperor in this city; and on the medals of the younger Gordian is an amphitheatre, which has occasioned some to attribute this building to him.

The Amphitheatre at Arles is of an oval form, its greater diameter being 455 feet, and its smaller 338 feet. It was two stories in height, and had around it sixty arcades, built of square stone throughout; it is now so occupied by buildings of various kinds, that it can scarcely be recognised as an amphitheatre.

The Circus. The chariot races of the Romans, which constituted their games during the time of the republic, supposed to be of Etruscan origin, were celebrated in the circus, which had an oblong form, terminated with a flat curve at one end, and a semicircle at the other. The arena was divided longitudinally by a spina, round which the chariots drove. The first circus was on the site of the Circus Maximus, though the buildings around were not erected till after the reign of Tarquinius Priscus. In the time of Julius Cæsar, it is said by Dionysius Halicarnassus to have contained 150,000 spectators. It appears to have been considerably augmented after that period by Trajan, as Pliny tells us it would accommodate 250,000. It was enlarged by Constantine, by adding to the number of seats, without increasing the dimensions of the course, so as to contain 360,000. For a long time this was the only circus in Rome; but another was formed in the Campus Martius, without the Flaminian gate, by the consul of that name, of which not a vestige remains.

Livy mentions the circus Agonalis, where the piazza Navona now stands: this was probably instituted by Numa Pompilius. The circi of Flora, of Sallust, of Nero, Hadrian, Heliogabalus, remain only in name, not one stone being left upon another.

Previous to the games, a procession of the images of the gods, drawn in sacred cars, took place, and before they commenced, the cars intended for the race were drawn up in front of the carceres, and prevented from passing out by a rope stretched to two termini: when the signal for starting was given, which was usually done by the emperor, this was dropped or withdrawn. A line, or furrow, filled with white chalk, called the *alba linea*, denoted the boundary that must be passed to win the victory.

The circus called Caracalla's is distant from Rome about two miles: much of the walls that supported the seats, and the foundations for the two obelisks which formed the spina, remain. Its length is 1602 feet, its breadth 260 feet: the length of the spina is 922 feet. The distance from the carcere, where the horses started, to the first meta or goal, was 550 feet. These structures were in the form of a parallelogram, one end of which was semicircular, and the other, where the carceres were placed, was the segment of a circle. Seven ranges of seats were placed around, on arches, in the same manner as in the theatres and amphitheatres. The segmental end was so arranged that the horses at starting should all have an equal distance to proceed to reach the first meta.

Riding schools, of a circular form, for training, triumphal arches for the victors in the

games to pass under, all faced and adorned with marble, formed part of these magnificent establishments.

The construction of this circus differs so materially from what we see in the baths of this emperor, that it is very doubtful whether it is not of a much later date. It certainly remains more perfect than any other known, and by some is considered the work of Gallienus.

Baths. These monuments of Roman magnificence contained all that could contribute to the health of the body, the improvement and amusement of the vast population.

Vegetius tells us that the reason the senate ordered the Campus Martius to be formed near the Tiber was, that, after exercising, the Roman youth might bathe; and 440 years after the foundation of the city, a *piscina publica* was constructed at the foot of the capitol near the Tiber: about the time of Augustus, baths were very generally in use; we find remains of them in England, and throughout the Roman provinces. As the names of the various apartments of the thermæ are all of Greek origin, it is inferred that the invention of them originated with that people: Socrates, Plato, Aristotle, and Hippocrates, refer to them.

To the original baths in the course of time were added the gymnasium, palæstra, spheristerium, &c., all foreign to the purposes and arrangement of the bath. At one time there were more than 800 baths in the imperial city: those of Paulus Emilius, Julius Cæsar, Agrippa, &c., were for the purpose of bathing only, and most of these were established by private individuals: but all yielded to the magnificence of the thermæ which succeeded them; the most remarkable of which were those of

	A. D.		A. D.
Agrippa	10	Antoninus Caracalla	217
Nero	64	Alexander Severus	230
Vespasian	68	Philip	245
Titus	75	Decius	250
Domitian	90	Aurelian	272
Trajan	110	Diocletian	295
Adrian	120	Constantine	324
Commodus	188		

Vestiges of these are to be found in various parts of the city, but the immense destruction to which they have been subject renders it impossible to trace them with any satisfactory result: those of Titus, Caracalla, and Diocletian, alone yield any instruction to the engineer. The restoration of those of Caracalla by M. Abel Blouet are so complete as to give a new existence to this species of edifices. They were the most extensive and the most magnificent of the edifices that adorned the capital of the ancient world; situated at the foot of Mount Aventine, between the walls of Rome and the Triumphal Way: as their name imports, they were founded by Caracalla, and finished in the fourth year of his reign, 217 of the Christian æra.

There seems to have been great symmetry in the arrangements and proportions of the exterior, but no decoration, that being reserved for the interior, which was regulated according to prescribed rules. Some idea may be formed of their magnificence, not only by the debris now visible of the various ornaments throughout the whole of the interior, but also by the monuments of sculpture which have been found there. The most remarkable are the Hercules of Glycon, the ancient Torso, the Bull called the Farnese, the Flora, two gladiators, the two vases of granite in the Piazza Farnese, the two beautiful urns of green basalt, now in the court of the Museo Vaticano, various terra cottæ, and an infinity of other sculptures and works of art. The last granite column of the great hall was removed from these thermæ, in 1564, and given by Pope Pius IV. to the Grand Duke Cosmo de Medicis; it is now on the Piazza Trinita at Florence, where it supports a statue of Justice in porphyry.

The general mass of the baths of Caracalla forms on the plan a quadrangle of 1011 feet by 1080. The principal entrance is on the smallest side, by an external portico, composed of two stories or rows of arcades one above the other, 53 in each row. These arcades have their piers ornamented with half columns, Doric above, Ionic below. They lead into a long gallery, and the piers which form it are ornamented with columns having pilasters opposite them.

The three other sides of the quadrangle show external walls without decoration, two of them being backed by Mount Aventine, a part of which was cut away for them.

The decoration was reserved for the internal façades, the enclosure of which contained the most important body of building, both for its ornament and the richness of its architecture. It was placed in the centre of this enclosure, between two spaces, that on the side of the portico being smaller, the other double the first, both having walks planted with trees. The internal façade of the grand enclosure in face of the portico exhibited a sort of amphitheatre or range of steps.

The construction of these baths is like most of the Roman works of the kind called

Emplecton, that is to say, masonry faced with triangular bricks, the whole bound together by rows of large quadrangular tiles, placed at certain distances over each other, and traversing the whole thickness of the walls; these were coated with cement; sometimes laminæ of marble were employed entirely to face them. From a review of all that remain we find that the most complete baths consisted of six principal apartments: the first, called the Apodyterium, was appropriated to undressing, and had shelves all round on which to place the clothes, and attendants, called capsarii, took charge of them. This apartment was also called Spoliatorium: all baths had not an apodyterium, and it appears from Lucian, that where this apartment was omitted, the frigidarium was used for its purpose. The apodyterium is not named either in the gymnasium of Vitruvius, or in the palæstri described by Lucian; it is probable that there was none in the gymnasium of the Greeks, and that the frigidarium supplied the defect.

The second apartment was the cold bath, called by the Romans Frigidarium; it was usually exposed to the north, and used as already stated. Galiani insists that the tepidarium and frigidarium were the same, but the paintings that remain to us prove the contrary, nor is it the opinion of Mercurialis and Baccio.

The third was the Tepidarium: its principal use seems to have been to prevent, by the temperate air which it contained, the dangerous effects of too sudden a transition from the extreme of heat to that of cold; thus in the paintings of the baths of Titus, it is seen between the frigidarium and the comamerata sudatio. According to all historians the frigidarium was united to the warm bath; hence Pliny calls it the middle chamber (cella media). Galen gives it the same name, and adds that thus it should be called, not only on account of its situation, as being the centre, but also with relation to its heat, "this chamber being as many degrees colder than the third, or the warm bath, as it was warmer than the first, or frigidarium." Although there were occasional bathers in the frigidarium and the tepidarium, still they were not generally so used, it being more common to walk through these halls or chambers at a slow pace, for it was the temperature of the air, and not that of the water, which induced so many to frequent them.

The fourth apartment was that called Laconicum, from the name of the stove which warmed it, and which was introduced from Laconia: it sent forth a dry heat, by no means, says Galen, calculated for warm temperaments. Dion tells us that those who sweated in the laconicum oiled themselves, and then entered the cold bath; it was originally intended for old men and infirm persons. According to Vitruvius and the various paintings which remain from the baths of Titus, it was contiguous to the tepidarium, and communicated to it a more temperate heat; it was a species of stove placed generally in the angle of the apartment, circular, and surmounted by a little cupola open at top; the flame of the hypocaustum entered the laconicum, and was lessened or increased by a brazen shield suspended to a chain, by means of which, says Vitruvius, the degree of heat to be given to the apartment was regulated. In the baths of Titus, instead of the brazen shield, a globe is represented attached to a chain, which, placed over the opening through which the flame arose, served to disperse and increase its power. It is undoubted that the laconicum was only the stove or furnace: the mistakes which have arisen concerning it were occasioned by its name being frequently applied to the apartment in which it was placed; this apartment in the above painting is called comamerata sudatio, and at length the part was taken for the whole: but Vitruvius makes an evident distinction, (lib. 5. chap. 10.) and he explains himself still more clearly in the following chapter, in which he reckons the stove among the apartments of the palæstri; "it should have," says he, "in one of its angles the laconicum, and in the other the warm bath." If, then, the laconicum was to be in one corner of the stove, it is clear that it was not the stove, but only a part of it; had it been so, as some insist, of what use was the comamerata sudatio? and why two stoves? The laconicum, or the stove, according to Vitruvius, had niches called sudationes, in which those who used these dry baths placed themselves, as shown in several ancient paintings. These niches were as high to the curve of the head as they were wide.

The fifth apartment was the Balneum, or warm bath, called Thermolousia; it was the most frequented. Its size, says Vitruvius, "must be proportioned to the number of bathers, its width a third less than its height," without comprehending the gallery called the *schola*, which was continued round, and terminated on the side of the basin, by a little wall of support; this gallery was large enough to accommodate those who waited for their turns. The middle was occupied by a basin called piscina, or by a bath called alveum, as shown in a painting of the ancient balneum: the place in which they bathed was immediately under the window from whence the light proceeded, so that no shadow should be cast by the persons walking about.

The sixth apartment was the Eleothesium or Onctuarium; in it were kept the oils and perfumes used by the bathers both on going in and out of the bath; it was so constructed as to receive a considerable quantity of heat from the hypocaustum.

The Hypocaustum was a subterranean furnace, the bottom of which formed an inclined plane, gradually falling towards the opening, by which the wood was put in; Vitruvius

calls it Suspensura. It should be formed, says he, of a pavement made of large tiles of a foot and a half, laid with such inclination that if a ball were thrown in, it could not remain, but must return to the mouth of the furnace. By this means the flame rose more readily, and extended over the whole suspended floor. This was formed of large tiles placed on little piers two feet high, made of clay, so prepared as to resist the action of the fire. The hypocaustum extended under the greater number of the apartments before named.

Besides the apartments especially destined for the use of the bath, there were several others connected with the exercises used before and after, such as the spheristerium, conisterium, coryceum, stadium, ephebeum, all of which made part of the gymnasium, but which did not exist in all baths, particularly in those of private individuals.

The arrangements cited were variable according to the fancy and pleasure of the owner. See Pliny's Laurentium. The following description taken from the Hippias of Lucian may give an idea of the various apartments in the ancient baths.

After passing the grand vestibule, we enter a spacious hall, for the use of those domestics who wait on their masters. On the left are the chambers, where they retire before quitting the bath; these are the most beautiful and agreeable of all; advancing, we enter the bath room, intended for the most opulent persons; through this apartment, on either side, are the places for putting the clothes; the centre of the space is very lofty, and well lighted, and contains three baths, of cold water, ornamented with Lacedæmonian marble; there are also two ancient marble statues, one of the Goddess of Health, the other of Esculapius: leaving this part by an oblong vaulted passage, there is a visible increase of heat throughout the building, though not disagreeably so, and you are conducted to a well lighted hall, in which are the oils and essences; it is on the right hand, and communicates with the palestræ; the two jambs of the doors are encrusted with Phrygian marble: in the contiguous apartment, this marble shines everywhere, even in the ceiling, consequently this is the finest of all; it is sufficiently large to permit of walking and taking exercise in it, and there are many convenient situations for sitting down. On leaving this, we enter the warm passage, which is extremely long; it is encrusted with Numidian marble, and leads to a well lighted and beautiful hall, painted in purple; here are three warm baths. To go out of it, it is not necessary to retrace your steps; a shorter way leads to the cold bath across the warm room, the heat of which diminishes by degrees; all these apartments are well lighted from the top. Hippias has shown much judgment in constructing the hall which contains the cold bath, so that it has the north in front; as for the others, which demand a greater degree of heat, he has exposed them to the south, south-east, and west.

By this description it appears that there was no apodyterium in the bath of Hippias; there were only shelves for the clothes at each end of the frigidarium, which contained three cold baths. The bathers then entered the warm passage which led to the onctuarium, whence, after anointing themselves, they passed into the spheristerium, which was the largest and finest apartment; when the exercises were ended, they went to the warm bath, by a passage in which there was sufficient heat to keep up that which had been produced in the spheristerium. Thus, when arrived at the warm bath, the bathers found little difference between it and the heat of their bodies, and after having taken it, they traversed an apartment in which the heat gradually diminished until they arrived at the frigidarium, in which were their garments.

The following description of the Greek baths is from Vitruvius. After describing the different apartments of the gymnasium, he says, at the right of the ephebeum was the coryceum, an apartment for shaving, dressing, &c.; near this was the conisterium, in which was kept the sand for the use of the wrestlers; in the corner of the peristyle is the loutron or cold bath; near this latter was the frigidarium, on going out of which was a passage which led to the propigneum; near the furnace in the corner of the portico further on, but by the side of the frigidarium, was the vaulted room for the sweating; its length was generally twice its width, and the laconicum was placed at one of its angles, opposite to that of the warm bath.

The arrangements of each of the apartments above named differs still more in the thermes of the Romans, although there is a certain uniformity in the plans: as there were two peristyles, we are justified in concluding that there was a double set of baths, as Varro and others prove incontestibly that the women's apartments were separated from those of the men; the observations of Martial and St. Cyprian by no means contradict this opinion; the improprieties they refer to relate to females of a licentious character. The separation of the baths is remarked in those of Caracalla; at least a large portion is preceded by a vestibule, which enclosed the principal body of the building. This part is divided into fifty vaulted rooms, separated from each other, but perfectly similar; some of the baths still remain, and from one nearly entire we can deduce the manner of its arrangement. It is preceded by a small vestibule; the place for the bath is 31 feet long, and 15 feet 3 inches wide. The basin which receives the water is in masonry with a course of freestone, which separates it 18 inches from the wall at bottom, and from the two return

walls. The open space of the basin, between the edges, is 12 feet wide and 15 feet long; the descent to it in front was by seven or eight steps, the whole width of the bath, four to arrive at the edge, and three or four to descend to the bottom, so that those who washed might seat themselves on the edge. The bath was lighted by an opening in the upper part of the lower wall. In this part of the thermæ a thousand persons might bathe at once: the water was only lukewarm, because it came from the warm baths of the thermæ, of which these latter formed the enclosure; it then flowed out by means of pipes into a large piscina, for the use of those who wished to exercise themselves in swimming.

In the return of the façades to the right and left were other baths for individuals of opulence or superior rank. Instead of basins were bathing vessels, of copper, marble, porphyry, granite, or basalt; there were also seats of marble or porphyry, a great number of which are still seen in Rome. Olympiodorus asserts that in the thermæ of Caracalla there were 1600 seats of this kind.

The rotunda or great hall was 111 feet in diameter; this was supposed to be the cella solearis or the hall of sandals, of which Spartian speaks in these terms: "Architects and mechanicians agree in saying that the cella solearis is an inimitable thing." There is reason to believe that it received the name of solearis because the bars of copper and brass which formed its floor, according to some, and its ceiling according to others, somewhat resembled the interlacing of the sandals of the ancient Romans. There were also plates of copper or brass which ornamented the *architraves* of the windows and doors, and other parts of the rotunda: it contained a great number of bathing vessels for warm water.

No subject has caused more discussion among the learned than the manner in which the numerous baths and bathing vessels were supplied with warm water. For if we suppose, which is by no means an exaggerated computation, that each vessel in the baths of Diocletian was capable of containing six bathers, eighteen thousand could be accommodated at once in the building. As there remains no vestige which can decide the various conjectures as to the means by which the water could be conducted into these vessels, it has generally been agreed to adhere to the explanation of Vitruvius. Baccius has treated this subject better than any other modern writer; he has imagined that the water might come from the reservoirs outside the thermæ, and that they were obliged to make use of machines to raise it to the height which his examination of the baths of Diocletian induced him to suppose was necessary: this idea was suggested to him, in consequence of finding that a vast number of pipes were taken out from an area, where there had never been any buildings, and were all surrounded by other pipes which came from the hypocaustum; the various difficulties in which this view of the subject is involved induced him, after serious reflection, to abandon any further hypothesis.

Piranesi has given the sections of two reservoirs which show that the quantity of water required to supply the baths of Antoninus Caracalla was easily obtained; it flowed from the aqueduct of Antoninus Caracalla, a part of which passed by the Appian Way. It appears by the plan of this vast reservoir, that immediately above the hypocaustum were twenty-eight vaulted chambers, forming two ranges of fourteen each, and communicating with each other; the sections show that above these chambers there were twenty-eight others, although one only communicated with the lower rooms by means of an opening, through which the water passed into the lower chambers immediately over the hypocaustum. Over all the rooms was a spacious reservoir, not very deep, but which occupied the whole length of the great reservoir, and in which the water was considerably warmed by the sun before passing into the chambers; this reservoir did not receive the water immediately from the aqueduct, but from a cistern, through which it was made to flow as slowly as possible, so that its surface should not receive the slightest agitation, which would greatly prevent the effect of the sun's rays upon it. When not required for the baths in the lower rooms, it flowed out of an opening in the side of the cistern, the water in the reservoir remaining the while in perfect repose. Thus the cistern answered two purposes, the preventing any agitation in the reservoir, and the carrying away the surplus water. When the twenty-eight vaulted apartments, which were immediately above the hypocaustum, became warmed, the heat they acquired augmented with the greater rapidity, as there was only one of the chambers which communicated with the outer air. Pipes were employed to give the water sufficient heat for the use of the bath; there were also pipes from the hypocaustum, which acted as reservoirs of tepid water to the lower rooms. When the hour for the bath arrived, the valves were turned, to allow the warm water in the lower rooms to flow into the baths, which it did with great rapidity; it rose in the thermæ to a perpendicular height equal to the surface of the great reservoir; its course was accelerated, in consequence of its great tendency to dilate or expand after being shut up in the rooms. If the pressure of the column of tepid water was not greater than the diameter of the column of warm water which flowed from the lower rooms, it was at least equal to it. To prevent the water from cooling in passing through the subterranean pipes, care was taken to surround them with other pipes which came from the entrance of the hypocaustum, so that these latter were in the centre of a

species of cavity, and acquired a considerable quantity of heat before the water entered them. Each of the chambers was within the walls, 49 feet 6 inches long, 27 feet 6 inches wide, and about 30 feet high; the number of superficial feet *of the bottom* of the chambers was 38,115, allowing 30 feet for the mean height; the quantity of water contained in the lower rooms amounted to 1,143,450 cubic feet, and it must be supposed that the upper rooms contained an equal quantity of water; consequently, if we give to each bather 8 cubic feet of warm water, supposing that the water preserved its heat for half an hour, sufficient time for a person to bathe, 18,000 persons consumed 144,000 cubic feet of warm water; according to this calculation, there was for the space of three hours, or till five o'clock in the evening, a sufficient quantity of water in the thermæ for 108,000 persons; it must, however, be acknowledged that the water cooled gradually in flowing from the upper rooms. The ancients do not inform us how they discovered the method of heating such large volumes of water, nor do we know whether it was an invention of the Romans or Orientals. We may reasonably suppose that it does not date further back than the time of Augustus, as Dion Cassius informs us, that it was in his reign Mæcenas built the first *warm bath* for swimming.

This, or some other similar method, must have been adopted in the thermes of the Romans. It is evident that the vases described by Vitruvius would have been inadequate to furnish water to those vast buildings which Ammianus Marcellinus compares to provinces; but they were used in private baths, as we shall relate.

The water for the baths, says Vitruvius, was heated by means of three copper vessels, so arranged that it flowed from one into the other; one was called the caldarium, the other the tepidarium, and the third the frigidarium; these vases were placed so that the

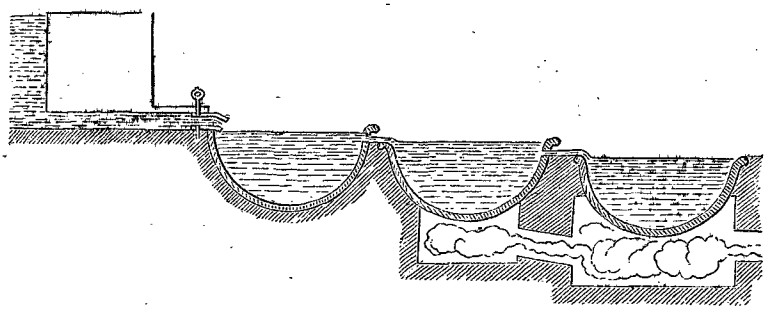


Fig. 132.

one which contained the warm water received as much tepid water from the tepidarium, as the latter did cold water; thus the same quantity was constantly maintained.

"It is not easy," says the Marquis Galiani, "to form a very correct idea of the situation of these vases on the furnace." Cæsare Cisarano and Caporali have figured them one over the other, or one within the other, placing the frigidarium on the tepidarium, and this on the caldarium, which stood immediately over the furnace; but the great difficulty in this arrangement is that the heat, by the tendency of the flame to ascend, would be more likely to act upon the frigidarium. Perrault, on the contrary, places the three vases on a level, and imagines there must have been syphons to conduct the water from one vase to the other; but without a piston, or some other expedient, the water could not rise to descend again. This Perrault does not explain. From what we can judge of the paintings in the ancient baths of Titus, it would appear that the three vases were placed on three steps, so that the bottom of the water in one is on a level with the opening of the other, whence it is easy to understand how they can flow one into the other; the Marquis Galiani, however, does not believe this to be the true arrangement, and imagines that it is made so in the picture merely to convey a better idea of this transversion from one vessel to the other. The following are his conjectures on the subject. "I think that these three vases are all on a level, the caldarium immediately over the furnace, the tepidarium a little further off, so as to experience the reverberation of the fire, rather than the fire itself; the frigidarium still more removed, on a heap of masonry which the flames could not touch. There was in the bottom a tube of communication from one vase to the other. From the caldarium to the baths was a pipe, whence by a tap the quantity of water required was drawn. Another pipe brought the water from the reservoir to the frigidarium, and maintained itself at the same level. All the drawings hitherto given to illustrate the descriptions of Vitruvius appear to require the superintendence of a servant to effect the transversion." Nevertheless this author leaves us to understand, that the operation was effected by itself, and without

the assistance of any one; according to him, it appears clear that three volumes of water being level, a vase fills in proportion to what it loses, attention being paid to the placing the bottoms of the vases each a little higher than the other, so that the caldarium should be the lowest, and the frigidarium the highest; there was no fear that the order of the transversion should be reversed; that inconvenience might even be obviated by stoppers placed at the entrance of the tubes of communication.

There was also another manner of heating the baths, which Seneca describes thus. "We have a species of high narrow vases, in the form of dragons and other things, in which pipes of thin copper are placed in a spiral order, that the water, by frequently circulating through the same space, may become heated. As the warm water flows out, the cold water flows in, and all that passes acquires the same degree of heat." Seneca shows the advantage of this proceeding, and tells us, that the tube through which the fluid descended, having no communication with the fire, the vapours were not mixed with the smoke.

Probably this was not a general method; there is reason to believe that it was only adopted by the rich. These vessels derived their name either from the animals which they represented, or from the quantity of water which they contained; there was necessarily a hole towards the bottom of the basin to conduct the warm water, and when the proper warmth was obtained for use, and the tap was turned to let it flow into the lower extremity of the pipe, the cold water entered the pipe by the upper, and descended as the warm water was drawn out: when the water which had first been heated had passed through the spiral tubes, the cold which had come in descended to the bottom of the pipe, after having been warmed in its passage, in proportion to the length and diameter of the pipe, to the quantity of water in the vessel, and to the degree of heat at which it had been maintained by means of the fire. The water was enclosed in such a manner as to prevent its sudden evaporation, which would have occasioned the introduction of cold water, and this would have abstracted from the pipe the degree of heat necessary for the use of the bath.

It is improbable that all these refinements of luxury and effeminacy were known to the Greeks, with whom the baths were only part of the gymnasium, whilst under the emperors the gymnasium formed part of the baths; it is quite certain that all such delicacies were not practised among the early Romans; in the best ages of the republic, the proceedings and customs of the bath were as simple as the edifices which contained them. It will be interesting to recal the parallel which Seneca has made between the bath of Scipio Africanus and those of his time.

"There are persons who consider Scipio as unrefined, for not having wide windows to his warm bath. How unhappy was he, say they; he knew not how to enjoy life! It is true that he did not always bathe in limpid water; it was often troubled, and even muddy in time of rain. But it was unimportant to him what water he used, for, using no perfumes, he washed merely to cleanse his body. His bath was small and dark, according to the custom of the ancients, for our ancestors imagined that a bath could not be warm without darkness. How delightful is it to compare the manners of Scipio with ours. This, then, is the hovel in which that great man bathed,—he who was the terror of Carthage, and to whom we owe it that our city was only once taken: he lived under that humble roof, he walked on that vile pavement; now, who would bathe thus? We think ourselves poor and miserable if we do not trample under foot mosaics and precious marbles; the marbles of Numidia are united to the stones of Thasus; the light is reflected from crystal, the water flows into the baths by taps of silver, and this is only for the people: what if I were to describe the baths of our freedmen, the crowds of statues, the multitudes of columns supporting nothing, only placed there for decoration, and on account of their dearness? With what noise does the water precipitate itself into the places destined to receive it. Our luxury has arrived at such a point, that we will no longer walk on any thing but precious stones. Instead of windows, the bath of Scipio had small openings in the stone walls, which, without diminishing their strength, only give the requisite light; now the baths would be called caves, if the windows were not of an immeasurable height, so as to admit the rays of the sun during the whole day, if we did not burn in bathing, and if from one's seat we did not see the country or the sea: formerly the baths were of small number, and without ornament, &c. &c."

We learn by this letter of Seneca to what a point of magnificence luxury was carried in the edifices destined for the bath, and the recital is quite conformable with the remains that are still left us; in the greater number we see the rich covering of the walls. In the bath room or hall recently discovered at Otricoli are still preserved fragments of the rarest marbles; its pavement was formed of that mosaic which is now the principal ornament in the Musæum Vaticanum. In the baths of Titus the walls were covered with marble to about the height of 10 feet, to preserve the paintings which decorated the walls from being injured by the splashing of the water. It appears that in these baths, a portion of the rooms, particularly those intended for the warm baths, had no window; at least none has been discovered.

When it became a custom to frequent the baths at night, luxury took advantage of the

necessity, by lighting them with lamps and candelabræ, which contributed greatly to their decoration. The most magnificent we now see at Rome were found in the thermæ; their light was thrown on crystal balls, according to Seneca, placed in the vaulting, or on the walls, so as to produce the most dazzling reflection: the introduction of glass as a decoration belongs to the time of Pliny, who calls it a modern invention; it did not exist according to him in the time of Agrippa, whose baths were decorated with coloured tiles, or a stucco called *Albarium Opus;* in one excavation, the vaultings were thrown into compartments of stucco, painted and gilt.

All the walls and masses composing them were built in rough masonry, filled up with smaller stones, the facings of which were of brick covered with stucco, ornamented with paintings, marbles, and precious stones. Generally every apartment was vaulted in the same kind of masonry; but in order to produce more lightness, tufa, pumice-stone, or extremely light lava, were used.

The large apartments in the baths of Caracalla were vaulted. The pavement was formed of masonry covered with stucco or mosaic.

The six apartments of which the ancient baths were composed were thus arranged: —

In the first there was nothing remarkable but the shelves or closets, in which were placed the clothes of the bathers.

In the second was the cold bath, called Lavacrum by the Romans, where was the basin, in which several persons could bathe at a time. It was of granite or marble, and sometimes of masonry covered with a strong cement, or capped by an edge of freestone: this cement acquired by time more hardness than stone; vessels were often made of a single piece, impenetrable to water; and as it is in the angles that square vessels generally became injured, care was taken to round them all internally; the bottom was so hollowed as to be deepest in the middle; they were finished by an edge or return on three sides only, called the labrum, and the centre alveum. Vitruvius, lib. 6. cap. 10. says, that the size or capacity of the basin should be proportioned to the number of persons intended to bathe, but they should not be less than 6 feet wide, two of which were given to the lower step and the lip; the length should be one and a half the width. The fourth side of the basin, which was that by which it was entered, was occupied by the steps which led to the bottom; beyond the edge or lip, and around the three sides, was a balustrade to separate those who were bathing from those who waited for their turn, on which account, between the balustrade and the walls of the hall, there was a gallery called schola, which was required to be sufficiently wide to accommodate all who were to replace the bathers; this gallery was paved in marble; the walls, as well as the cement which covered them, required to be made with care and precaution, on account of the humidity occasioned by the evaporation of the water. Perrault, in his translation of Vitruvius, imagined that the baths were lighted by an opening in the centre of the vault; but it appears that Vitruvius himself says, that the bath should be placed under the light of the window, so that the shadow of those who are around it should not intercept the rays, which would lead to the supposition that there was no gallery on the side of the window.

There are several of these cold baths in the thermæ of Caracalla, one of which remains in a vaulted hall, preceded by a small vestibule with a portico, said to have been added by Septimius Severus. The apartment is 31 feet long, and 15 feet 3 inches wide; the basin is in masonry, with an edge in freestone, which separates it 18 inches from the bottom wall, and the two returns: the hollow of the basin between the edges is 12 feet wide, by 15 feet long: the descent is in front, by seven or eight steps, which are the whole width of the hall, viz. four to arrive at the edge of the bath, and three or four to descend to the bottom, so that those who washed could sit on the edge, which was round the three sides. The bottom and sides are covered with a very thick and hard cement; the surface being crystallised, which probably greatly contributed to its hardness; such incrustations are apparent in all reservoirs and receptacles for water throughout Rome, the water having the property of petrifying, if we may so term it, the surface of all cements, which are moreover well mixed, and made with the greatest care.

This hall was lighted by a semicircular window opened at the top of the lower wall, against which the baths were formed.

Along the side of the thermæ which is to the north-east there are fifty apartments, apparently destined for the same purpose, so that a thousand persons might bathe at a time; the water must have been tepid, for it appears by the pipes and conduits which are left, that it came from the warm baths of the great thermæ, of which these baths formed, as it were, the inclosure; between the baths, and at nearly equal distances, were the remains of four large staircases, of two rampes, which led to the thermæ, the soil of which was 20 feet higher than that of the baths. The whole edifice was built on the declivity of the mount Aventine, so that the first served as the substructure or foundation of the upper soil.

All the walls and vaults are in masonry, faced in brick, and covered with cement of mortar; the pavement is in masonry, which proves that the baths were only destined for the common people.

Construction and Arrangement of the Furnaces and Conduits for Heat.— Vitruvius gives very circumstantial detail on this subject. "We must begin," says he, "by making an inclined area, laid with large bricks 1½ feet square. This area should be so disposed, that a ball thrown in at the door of the furnace should not be able to stop in any part, but should return to the door; in this manner the flame or heat should extend through all the turns and voids of the conduits formed under the pavement.

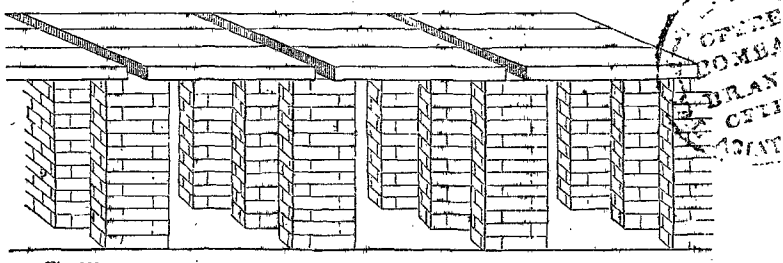


Fig. 133. HYPOCAUSTUM.

To form the double floor which covers these voids, and which Vitruvius calls *Suspensura*, there were constructed at equal distances little brick pillars, 8 inches square, at 2 feet distant from centre to centre. These pillars should be about 2 feet high, in the part where the inclination was the lowest. When well levelled, bricks 2 feet square were so placed, that each pillar received the angles of four bricks, and there remained round each pillar 16 inches of void: above this brick floor, carried by the pillars, was spread a layer of broken tile mixed with chalk, covered with a fine cement, or a pavement of mosaic; that the bricks which rested on the pillars might not break before the whole had acquired sufficient consistency to sustain itself independently of the brick, the space between one pillar and the other was arched.

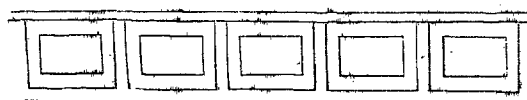


Fig. 134. PLAN OF PIPES OF TERRA COTTA.

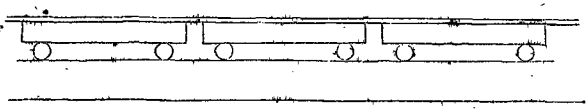


Fig. 135. SECTION OF PIPES AT POMPEII.

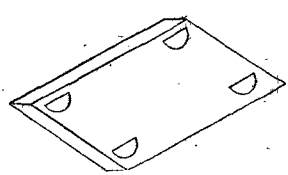


Fig. 136.

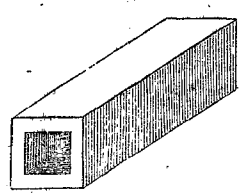


Fig. 137.

Among the ruins of Pompeii are the remains of a private bath with stoves; the double floor in suspensura formed nearly in the same manner, with this difference, that instead of little pillars in brick, they are pipes of terra cotta, made on purpose; these pipes are terminated by two square tiles, with a hole in the middle; they are 19 inches high, and about 4½ inches in thickness about the middle: the square at bottom is 8 inches, and that at top 6 inches; no doubt this form was given for the purpose of a greater base; the pipes were placed upright on an inclined bed, as prescribed by Vitruvius; this is laid in large bricks, 8 inches square, each pipe so placed that it covers the joint where the angles of the tiles unite, so that they are 18 inches apart from centre to centre. Above the pipes is a platform made by a double row of bricks, also 18 inches square, each placed on four pipes; on this double platform is a bed of mortar, made of pozzolana, covered with a mosaic pavement.

The place which served as a stove was small; its plan is a rectangle, 10 feet long, by 5 wide, terminated by a niche forming a seat at bottom; the entrance is by a very small door, which is at the other extremity in an angle: as the walls are half demolished, and they have scarcely more than 2 or 3 feet of elevation, it is not possible to ascertain whether it was

vaulted, which is very probable, but it is still less possible to decide in what manner it was lighted.

The pavement of this stove, as well as of the warm bath at the side, is raised about 2 feet 6 inches above that of the place in which is the entrance of the furnace. There is also the remains of a leaden pipe which conveyed the water into the warm baths; its external diameter is about 2¼ inches. In these apartments were the vases or kettles in which the water was warmed; there is no vestige of the laconicum, but at the side of the furnace there is a square recess in the wall with a bench, the situation of which must have been much warmer than that of the niche at the bottom, so that persons could place themselves either in one or the other, according to the greater or less degree of heat desired.

In another part of the same ruins was a stove of a circular plan, with a step and niches around; it is lighted by a round hole about 1½ feet in diameter, made in the middle of the vault; this hole might have been the situation of the brazen shield, to be raised or lowered for the purpose of increasing or diminishing the heat.

A bath was discovered at Rome, in which the basin was covered with a coating of cement so hard, that it was impossible to dissolve it sufficiently to analyse its substance, it was a Roman palm thick, and capable of resisting not only the heat of the water, but the action of any heat whatever.

The Romans having introduced the use of the bath wherever they had carried their arms, we find remains of them in their most distant provinces. At Wroxeter in the county of Shropshire was discovered a small square room, the pavement of which was constructed in the following manner: — there were four rows of pillars in brick 8 inches square, put together with very fine red cement; they were placed on a bed of bricks a foot square; the platform above the pillars was formed by bricks 2 feet square, and of extraordinary hardness; the bed above was composed of a mortar of broken tiles and large gravel; round the internal walls were fixed by iron clamps pipes whose inferior extremity abutted against the platform of large bricks, which formed the floor above the pillars; the other end came to the surface of the upper pavement; it was covered by a row of bricks; each pipe had two opposite holes to communicate the heat.

Six miles from Chester, a part of a bath recognised as Roman construction was discovered. in which was a hypocaustum surrounded by walls cut in the rock. The lower pavement was of brick laid in cement; the platform was supported by brick pillars, which appeared to have been polished, and had in several places holes above which were brick tiles, to distribute the heat. On some of the bricks were inscribed LEG. XX., whence it was inferred that this hypocaustum had been constructed by the twentieth legion, which was called the "Victorious."

With regard to the vaults of the warm baths, Vitruvius says that it is better to make them in masonry than in carpentry, but when a floor is required, there should be underneath a *filling-up* of terra cotta, made in the following manner. Bars or arcs of iron must be suspended to the carpentry with clamps of the same metal, placed sufficiently close, that from one to the other there may be put flat tiles without edges, so that a vault may be formed isolated from the floor and entirely suspended by iron; over it should be laid a coating of clay mixed with hair, and the under side towards the pavement should be first covered with cement, and then finished with polished stucco; the vault would be better if double, in order that the vapour, which might penetrate the first, should be stopped by the second, and thus preserve the carpentry from humidity.

The Thermæ discovered in 1824 at Pompeii are highly interesting, as they exhibit the arrangements of such an establishment out of the Imperial city; they occupy an irregular quadrilateral space north of the forum, and were entered from the street by a small passage which opened into a court 60 feet in length, on two sides of which was a Doric portico, on the other a crypt, over which was a second story. At the opposite angle of the court was another exit, where was situated the latrina; to this succeeded a sort of pronaos with seats, which was vaulted and lighted at night by a lamp, so placed that its rays fell into the chambers around. This lamp was protected by a circular convex glass, the fragments of which were discovered. From the court the bathers passed to another chamber, in which were found above 500 lamps, made of terra cotta, with various devices upon them; this room was the frigidarium, and served also as the spoliatorium, apodyterium, or apolyterium, or the place where the clothes were left; many holes still remain in the walls in which the pegs were inserted, on which were hung the garments of the bathers, and which were called Caprarii, probably from resembling two horns. This spacious chamber is vaulted from a projecting cornice, decorated with griffins and lyres richly painted. The vault is panelled, coloured red and white, and the pavement is mosaic. The walls were coloured yellow, around which was a stone seat with a step a little elevated above the floor. At each end was a window, similar to the one remaining on the south end, and which opened upon the cemented roof of one of the chambers. This window had a plate of thick glass, slightly ground on one side, and secured by copper bars. Another room contained the natatio, or swimming bath; in the time of Pliny, it was called baptisterium. This chamber is perfect;

nothing is wanting but the water to fit it for its purposes, which gushed from a copper pipe, about 4 feet from the floor, and fell into the cistern. The plan of this room is a circle enclosed in a square; in the angles are four alcoves; the diameter is 18 feet 6 inches, and round the whole runs a walk about 2 feet 4½ inches wide. The piscina, 12 feet 10 inches in diameter, is surrounded by a seat, 11 inches wide, at about 10 inches below the lip, and 2 feet 4 inches from the bottom; so that the water was about 3 feet in depth. A convenient step led out of the bath, and proper channels were provided to empty it. The whole of this arrangement was of white marble. The dome or roof was conical, painted blue, and had an aperture near the top toward the south-west, which admitted light and air; the side walls were painted yellow with portions green. The alcoves, which were 5 feet 2 inches wide, and 2 feet in depth, were painted blue, and the hemispherical parts red. The cornice surrounding the room was 8 feet from the floor, 18 inches high, and coloured red; this was ornamented with stuccoed figures on foot, on horseback, and in chariots.

The tepidarium, a beautiful vaulted apartment, discovered in 1824, contained three bronze seats, inscribed with the name of the donor, Marcus Negidius Vacula. The legs resembled those of the cow, the head of the animal forming an ornament to the upper parts. This apartment was warmed by a large foculare or brasier given by the same person. This bronze vessel with thirteen battlemented summits, and a lotus at the angles, was 7 feet long, and 2 feet 6 inches broad. In the centre was a bronze cow. To resist the heat of the embers the bottom had brass bars, on which were bricks, supporting pumice-stone, for the reception of the wood ashes or embers. The pavement of the tepidarium was of white mosaic with two small black borders; the ceiling was painted, the walls crimson. Under the pavement was a continued hypocaustum to warm the apartment.

Round this room, 4 feet 3 inches above the pavement, and 1 foot 2 inches in height, was a small cornice, on which figures of giants, about 2 feet in height, formed of terra cotta, were placed, projecting about a foot from the wall, and distant about fifteen inches apart; their arms stretched out to assist in bearing the superimposed weight of an entablature 1 foot 5 inches in height, which rested upon the heads of these telami.

The caldarium, on account of the steam that was produced by the laconicum, was not very highly decorated; there was not only an hypocaustum under the floor, but the walls were constructed so as to allow warm air to circulate around it. This was effected, not by flues, but by a lining of tiles, connected with the outer wall by cramps of iron, a space of 4 inches being left for the hot air to ascend from the furnace below; it was lighted by windows from the top. The walls are painted yellow, the pilasters and cornice red, and the alcove blue and red. In the centre of the latter was the labrum, of white marble, 8 feet in diameter and 8 inches in depth, in the middle of which was placed a brass tube for throwing up the water. This chamber was 37 feet long and 17 feet 4 inches in width.

From the pavement of the caldarium, which was of white tesseræ with two small black borders, the bathers ascended by two steps to a third, also of marble, 16 inches in breadth, which formed the brink of the vase of hot water. A step, dividing the whole depth of the cistern, which did not exceed two feet, permitted them to immerse themselves by degrees in the hot water.

The entire length of this cistern is 15 feet, and the breadth 4 feet, so that ten persons might at one time occupy it. The hot water entered at the angles immediately from a cauldron placed on the other side of the wall. In the roof were four openings for the admission of light, which probably were glazed or closed with vela of linen cloth.

The caldarium was the bath, or the vessel containing the hot water, adjoining which was the laconicum, for the purpose of producing respiration. The furnace contained three cauldrons, placed one above another, in which were three varieties of water, that at the top being the coldest, that immediately over the furnace always boiling, and as it was discharged, a fresh supply was obtained from the middle cauldron, which was in a tepid state. These cauldrons were supplied by pipes from leaden cisterns called Miliaria.

When we survey the ruins of the baths, we cannot but regret that we have not establishments in all modern cities, where the inhabitants, both rich and poor, might attain the first elements of health: cleanliness by the ancients seems to have been much more considered and encouraged than by us, for there were hot and cold water baths established in every town. The following verses of one of the poets give some idea of what a Roman underwent before he commenced his toilet.

> "Scabor, supplilor, desquamor, pumicor, ornor,
> Expilor, pingor," &c. &c.

And to accommodate the multitude, many of these washing and bathing establishments were upon such a scale as to resemble towns, where every citizen, whatever his condition, could enjoy daily, without trouble or expense, the luxury of the bath. Our crowded and populous manufacturing towns need the use of thermæ more than the provinces of the Imperial city; the workmen, early and late, should have the opportunity as well as induce-

ment to enter the bath; and in all well regulated workshops, it ought to be made a duty of the first consideration, to adopt habits of cleanliness: were this done, health would be assured, and longevity be much more frequently met with.

At Bath the Romans had several establishments for bathing; hypocausts and tubulated tiles are constantly met with when fresh ground is broken. This city in the Itineraries of Antoninus and Richard of Cirencester is called Aquæ Solis; and there are found also altars to Sulinis Minerva, the Solar Minerva, or the Minerva Medica, which clearly indicate that it was much resorted to by invalids in those days.

Baths at Baden-weiler, a plan of which is given in the edition of Vitruvius published at Berlin by Rode, contains a set of baths for men and women, with the apartments required by those who attended them. A, was the position of the hypocaust, B, the furnace, C, the

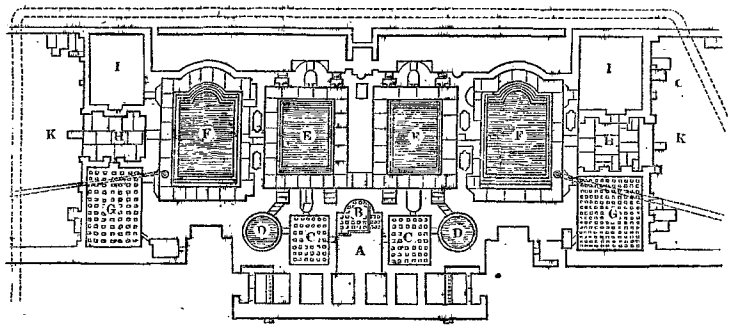


Fig. 138. BATHS AT BADEN-WEILER.

caldaria; D, vaulted sudatories; E, tepidaria; F, frigidaria; G, rooms which had floors, like those of the caldaria, heated by the stoves; H, vestibules; I, elaeothesia, and K, exedrae. This arrangement forms one of the best illustrations to the description given us by Vitruvius, although upon so small a scale.

Baths at Stura.—Near Antium, at the mouth of the small river Stura, now called the Conca, are the remains of some baths built in the sea. A, is a grand court surrounded by

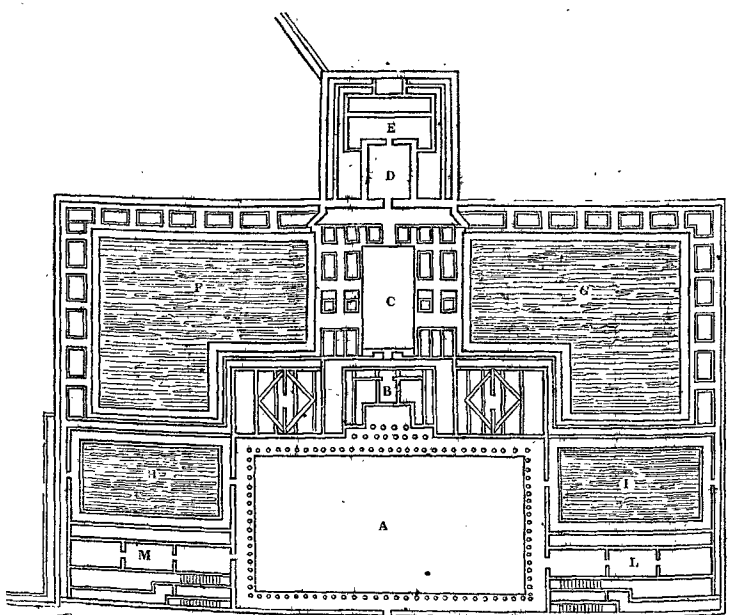


Fig. 139. BATHS AT STURA.

columns; B, is the vestibule conducting to the baths; C, a hall communicating with the sea baths; D, is now occupied by the tower of the Stura; E, projects into the sea, at the extremity of which is the mole; F and G, are large, and H and I, smaller swimming baths, surrounded by rooms for the convenience of the bathers; L, M, are passages and approaches from the side towards the town.

Baths at Nismes, situated north of the city, are supplied by a clear stream, and have been decorated with considerable taste: Palladio, Clerisseau, and many French architects, have shown great skill in their restoration. A, is a large court, surrounded by a covered peristyle, B; the lower portion of the baths is shown at C; the source of the water is at D, which is entered by winding stairs at E, E; a bridge over the canal remains at F;

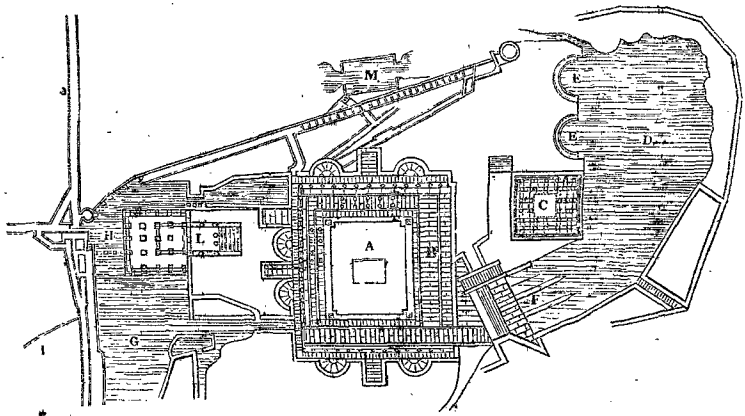


Fig. 140. BATHS AT NISMES.

another reservoir is shown at G, which passes by the canal H into different private baths; I, is the direction given to the waters on issuing from the baths; L, is a small temple dedicated to the presiding divinity, and M, another small reservoir.

For warming their houses the Romans had a very simple and admirable method; the word *caminus*, from the Greek *kaminos*, whence our word chimney is derived, would indicate that they had flues something like our own. The etymology leads to this supposition, but we must take into consideration the various uses and forms to which it alluded. The terms *caminus* and *focus* were applied both to the place in which the fire was lighted and to the fire itself; hence it is doubtful to which they referred. Focus is used indifferently for a brasier or any of the portable fireplaces in which charcoal was burnt, or for a place where wood was consumed.

Vitruvius, in his account of houses to be built in the country, used the word focus when alluding to the kitchen fireplace. The kitchen, this author states, should be placed in the warmest part of the court, adjoining to which should be the stalls for the oxen, with the mangers at the same time towards the fire and towards the east, for oxen with their faces towards the light and fire do not get rough coated.

The word caminus probably meant at first a furnace for melting metals, in which a crucible was made use of; and Pliny has the word applied to a smith's forge. It also indicated a hearth.

Seneca, in his 90th Epistle, gives us an account of a method introduced in his day to warm an apartment. A large stove, or several, were formed in a vault under a building, and these being filled with burning embers, the heat was conveyed away into the several rooms by means of pipes built up in the walls, the upper ends of which were ornamented with a lion's or a dolphin's head, and through their mouths passed the warm air; these could be shut or opened at pleasure. These pipes, made square, of terra cotta, were laid in indents in the side walls around the whole apartment in a perpendicular direction, and acted as so many flues or chimneys from the fireplace below. This was a species of hypocaustum under the floor, like that described in the baths, and the little smoke produced by burning wood in the prefurnium passed up the numerous perpendicular flues in the wall; these, being made of thin burnt clay, radiated all the heat they absorbed into the room, and very little could have passed away after having circulated through such a length of pipe, where the draught was so much divided.

The manner of warming our greenhouses bears some resemblance to this method, particularly where the flues are carried under the pavement, within a walled trench, into which

air is admitted, and, after warming, is suffered to pass through apertures in the pavement prepared for the purpose. In the Roman hypocaustum the fire was laid at the mouth or at the foot of the prefurnium, and the air passed over it, in the same way that it does in a malt kiln, into a chamber under the floor of the apartment to be warmed. The floor, being larger than the top of the kiln, was supported by small pillars, and the heat, instead of passing through it, was made to circulate around the walls and lose itself in its circumambulation. These species of hypocausta were common in the country houses of the Romans. Under the rooms of many of their villas are found a hollow space, from 2 to 3 feet high; the floor being supported upon flat tiles which rest upon a series of small brick pillars built with fire-clay, or with a cement not containing any calcareous matter likely to be acted upon by a strong heat. Along the sides are still found the square pipes of burnt clay which carried off the rarified air from this subterranean chamber into the apartments around or above the triclinium or room immediately over the space first warmed. A narrow passage usually led to the mouth of the furnace; this being vaulted, and having an aperture at the end to admit air, acted as a blower to the furnace or blazing wood placed at the mouth of the hypocaustum.

De la Valle observes that the Persians warm their apartments by stoves made under ground; these are a species of cauldron, in size and shape like a small barrel, which are placed in an iron vessel filled with burning coals. The barrel or stove is covered with a wooden top over which is laid a carpet; the embers are excited to burn more strongly by means of a small tube, which acts as a blowpipe: here the air admitted into the barrel becomes warmed, as it does in the oven of a French poele, and may be diffused throughout the apartment.

By the introduction of warm air, thus admirably circulating throughout a Roman house, there was no need of a chimney shaft like those we require to carry off the smoke from a coal fire; and Vitruvius makes no mention of such contrivance. He says that cornices and carved mouldings should be omitted in rooms where fires are lighted, because they are subject to be injured by the smoke. It is true they had open fires, as they have in Italy at present, made in chafing-dishes or brasiers, which were placed in the middle of the apartment. These are very handsome, and are supported upon a tripod, or made to resemble a walled town with towers in miniature.

The wood used was the white and common willow, which produced little smoke and few sparks. They first peeled off the rind, and then laid it some time in water, after which they exposed it to the sun and air to dry. Sometimes this wood was soaked in oil lees, or had oil poured upon it, or was partly burnt in the open air, before it was introduced into an apartment, when it was called ligna cocta, and under such a term it was sold at Rome. The warehouses called tabernæ coctiliariæ were very numerous, and many persons were employed to prepare wood for fuel, or to rid it of its smoky qualities.

Harbours and Buildings in Water.—When a harbour was to be formed, the Romans made choice of such situations as would ensure safety to their vessels in stormy weather, and preferred those bays which were protected by long promontories jutting considerably into the sea, and forming curves and angles. Around these, porticoes, arsenals, and market-places were established, and the mouth of the harbour was secured by iron chains, suspended by means of machinery contained in two towers at the entrance. When nature had not so provided, and the shore was flat, they constructed piers by throwing into the sea heaps of stones, which they projected to a vast distance in the following manner. An earth was procured between Cumæ and the promontory of Minerva, which, when mixed in one proportion of lime to two of the earth, had the property of hardening under water. When the situation of the pier was determined upon, dams were formed in the sea by driving oak piles, secured firmly together with chain pieces. Between two ranges of piles thus driven, the earth was taken out, and the bed properly levelled; mortar, composed as above, was then thrown into the space between the piles, together with a proportional quantity of stones, until it was entirely filled. If the sea was too deep or violent for this method to be pursued, they constructed on the margin of the sea a foundation of the greatest possible strength, with courses of stone laid horizontally throughout rather less than half its length; the remainder, which was towards the sea, was made to incline. On the side towards the water, and on the flanks of the inclined plane, walls were built, projecting over the face eighteen inches, after which the whole was filled with sand to the level of the horizontal part. On this sand they commenced building a wall, which was raised as high as possible without incurring danger; this was left for a couple of months exposed to the action of the air, that the whole might harden. The walls inclosing the sand were then removed, and the sea, washing against the sand, speedily carried it away; the whole mass then sliding on the inclined plane, was shot into the water, and this sort of operation was continued until a sufficient number of artificial blocks were constructed to form the mole or pier required. Sidonius Apollinaris, in his panegyric of Anthemius the consul, says: "The new land advances into the sea, and its mass contracts the old ocean; Dicarhean dust when thrown into the water becomes solid, and the hard mass sustains fields, thrown into the foreign waves." This kind

of work was accomplished by merely throwing into the ocean the earth obtained from Puteoli, which, when immersed in the sea, became as solid and compact as a hard rock: this earth was a compound of alumina, bitumen, and sulphur, not differing much from that found at Cyzicena, which, when cut into large blocks and sunk under water, had the property of hardening. The younger Pliny, lib. vi. let. 32., writing from the neighbourhood of Ostia, describes the progress made at the port of Centocellæ, thus enabling us to judge of the method by which the Romans conducted such operations. "The left hand of the port is defended by exceeding strong works, and they are now employed in carrying on the same on the opposite side. An artificial island, which is rising at the mouth of the haven, will break the force of the waves, and afford a safe

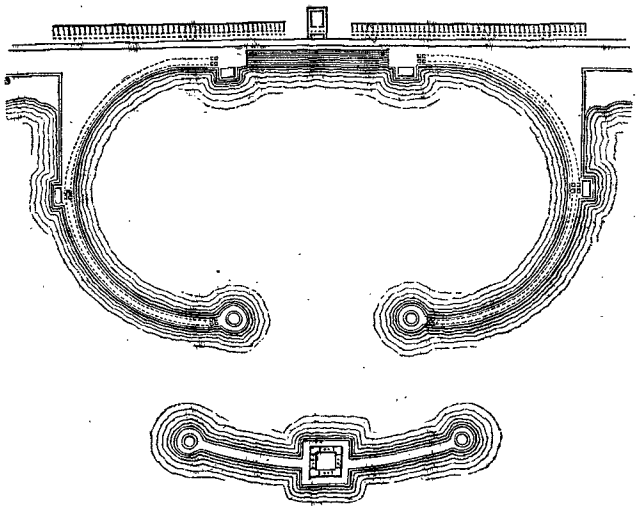


Fig. 141. CENTOCELLÆ.

channel to ships on each side. In the construction of this wonderful instance of art, stones of a most enormous size are transported either in a large sort of pontoon or raft, and, being piled one upon another, are fixed by their own weight, and gradually accumulate in the manner of a natural mound. It already lifts its rocky back above the ocean, while the waves which beat upon it, being tossed to an immense height, foam with a prodigious noise, and whiten all the sea around. To these stones are added large blocks, which, when the whole shall be completed, will give it the appearance of an island just emerged from the sea." The above was written from his villa at Centocellæ.

Ostia was formed into a port in the year of Rome 132, by Ancus Martius, who also constructed the first wooden bridge over the Tiber; and here, in after times, were three separate ports, affording secure retreat to vessels on that dangerous coast, constructed by Augustus, Claudius, and Trajan: the latter, that alluded to by Pliny, was destroyed by the changes which took place in the bed of the Tiber. The ancient port of Ostia was about half a league from the sea, and five leagues south-west of Rome, near the mouth of the Tiber. At Porto, now a small village, and a league from Ostia, on the other side of the Tiber, are considerable remains of the town which the emperors Claudius and Trajan caused to be built. The basin of the ancient port of Trajan may be seen, with fragments of many of the buildings represented on his coins.

The port constructed by Claudius, in advance of that of Trajan, was amongst the boldest executed by Roman engineers: — an oval sheet of water, enclosed from the ocean by broad and spacious moles, affording a safe haven for vessels which navigated the western shores of Italy: an artificial island lay between the horns of these two moles, with towers at each extremity, containing machinery and tackle of various kinds, by which the boatmen could at all times enter safely. These constructions must have been a work of prodigious labour; their solidity is attested by the writers of the time, particularly by Pliny. In the middle of this island stood a pharos, before which was the colossal statue of the emperor Claudius. Fire was placed, at the approach of night, in the upper story of this lofty structure, which could be seen from a considerable distance. Orders of the purest architecture decorated three of the stories, and ingeniously

contrived rooms and staircases served for the use of the officers and men to whom this part of the port was entrusted. Covered galleries and porticoes standing high above the sea, and stretching far into the ocean, invited mariners to enter, and produced an imposing effect to all who navigated these seas.

The port of Claudius united to that of Trajan gives us an idea of the arrangements in use during the reign of these emperors: magazines for stores of all kinds, docks, slips, and other buildings usually found in a modern port, were here executed in a manner equal to those of the imperial city.

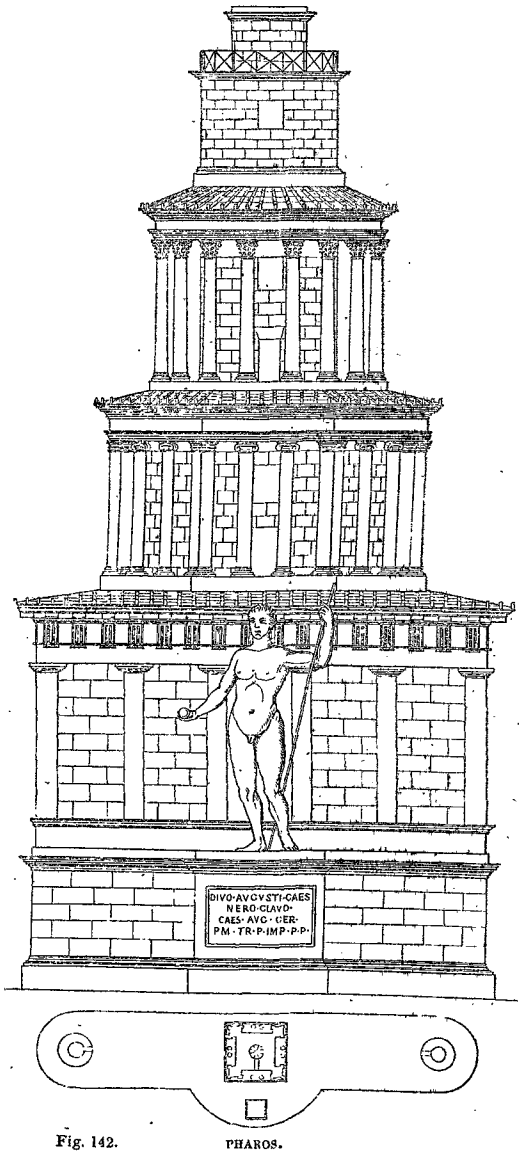
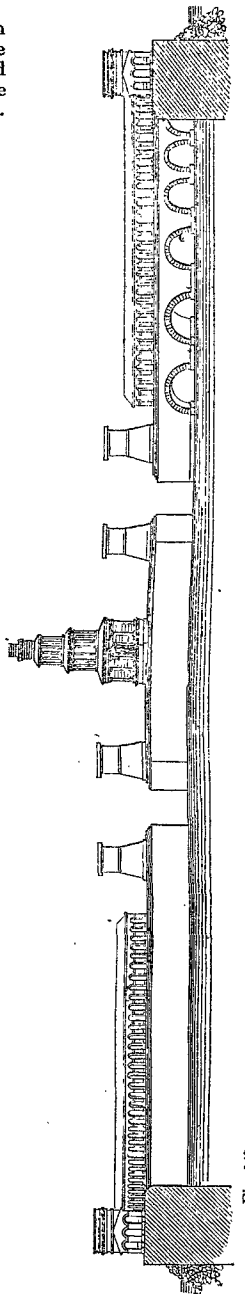


Fig. 142. PHAROS.



SECTION THROUGH CLAUDIUS' PORT.

Fig. 143.

Temples, triumphal arches, rostral columns, and trophies, occupied the spaces not used by the mariners, and noble roads conducted the merchandise and warlike stores from thence to every part of the empire.

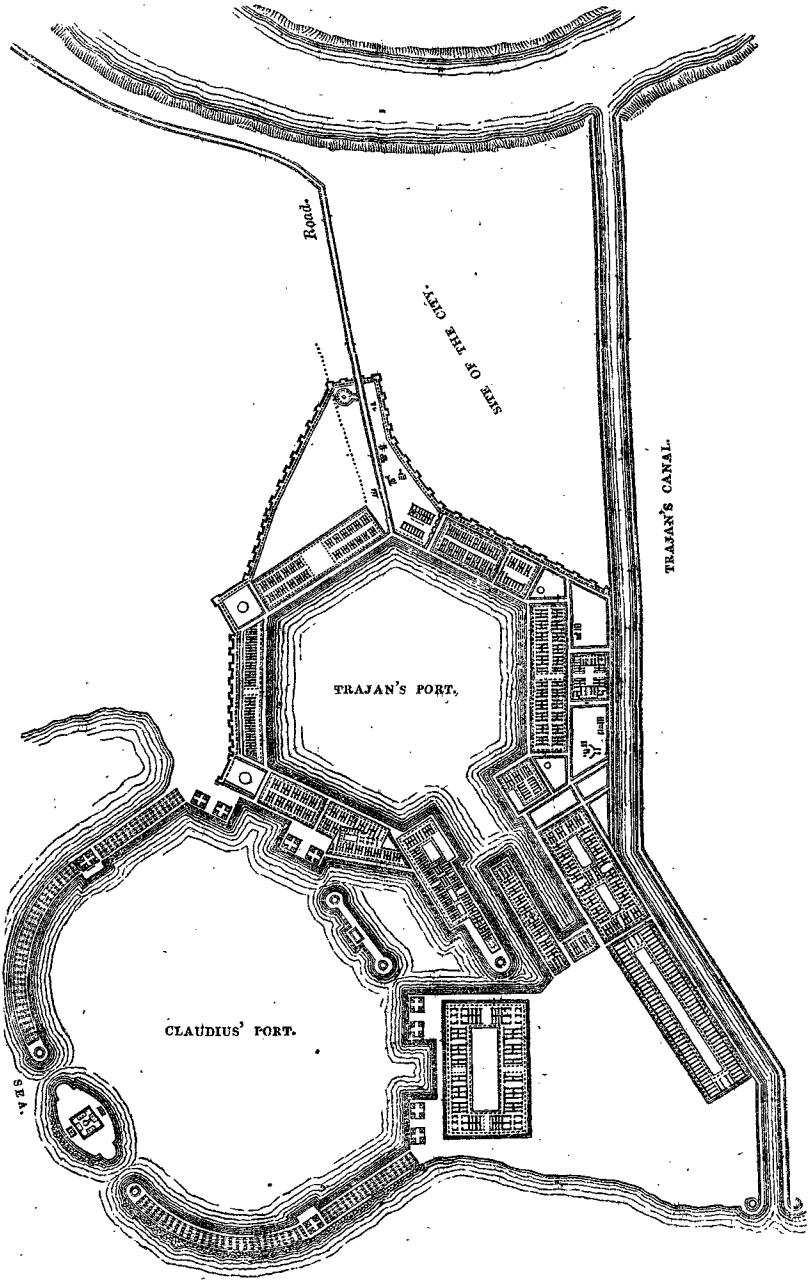


Fig. 144.

Modern nations have neither excelled the Romans in works of this kind, nor rivalled them in boldness, by lifting out of the ocean walls so lofty and durable as many they have left us; their engineers formed artificial islands as well as breakwaters, and in whatever they undertook, they seem to have blended the arts with a thorough knowledge of construction. The medals of some of the Roman emperors show the taste bestowed upon these public works; and no bounds seem to have been set to the area they walled in from the sea. One of their ports must have had the character of an extensive island, as its connection with the land could hardly be seen, at the first view, from its length and the stretching out of its moles. The ports called angiportum were very narrow, and considerable skill was required to work vessels into them. Juvenal notices the extent of some of the moles constructed in his day, and observes that such ports as those of Claudius, the work of nature and of art, were wonderful for the extent of their foundations, laid at the bottom of the sea.

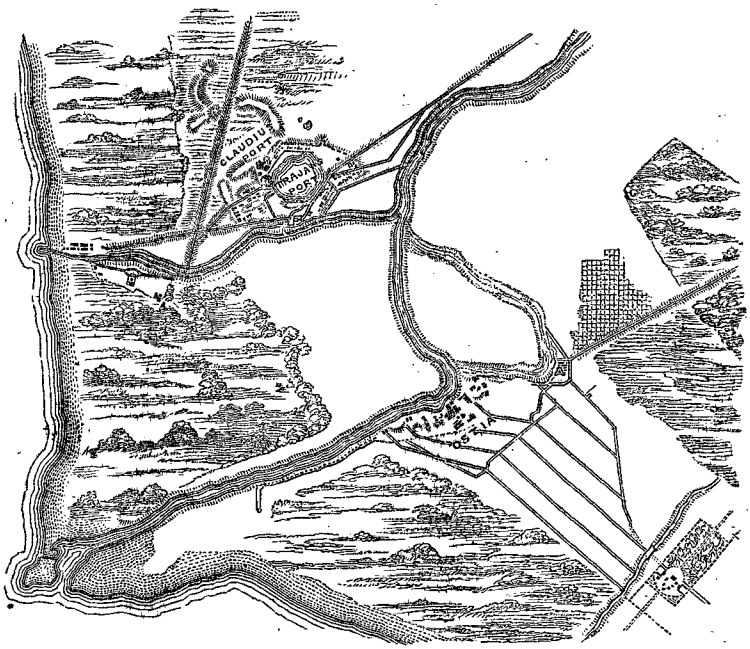


Fig. 145. PORT OF OSTIA.

We find Roman harbours well calculated to receive and protect the vessels which entered them: at the mouths of rivers they drove in ranges of piles, planked over, and covered with pitch; at the extremity of each mole was a tower or contrivance by which a chain or boom could be stretched across the entrance, and protect the port from any sudden attack of an enemy. When an artificial port was formed on the coast, for the security of ships, they constructed a mole, in a circular shape, or with vast arms, like *crabs' claws* (*chelæ*), or, as Cicero terms them, with *cornua: Epist. ad Attic.* lib. ix. ep. 19. A Roman harbour, or *Claustra*, was entirely shut in, and none could gain admission without the consent of the mariners who occupied the watch towers at its entrance.

That part of the harbour by which you entered was called *Ostium* and *fauces*, or the mouth between the arms of the semicircle: when the vessels had entered, they were made fast to the shore, or lay at anchor. Where a flat shore presented itself, the vessels on their arrival were run backwards upon it, with their heads towards the sea, when the rowers, *inhibere remos*, hung up their oars out of the reach of the waters, that they might not be broken: sometimes they were attached to the sides of the vessel; according to Ovid, "to the ship's sides the seamen hung their oars."

The port of *Ostia*, or mouth of the Tiber, having silted up, we trace those of Claudius and Trajan, and the diversions of the river far from the present shore; the whole features of the coast are now materially changed, and a wide marsh lies in front of the port of Claudius.

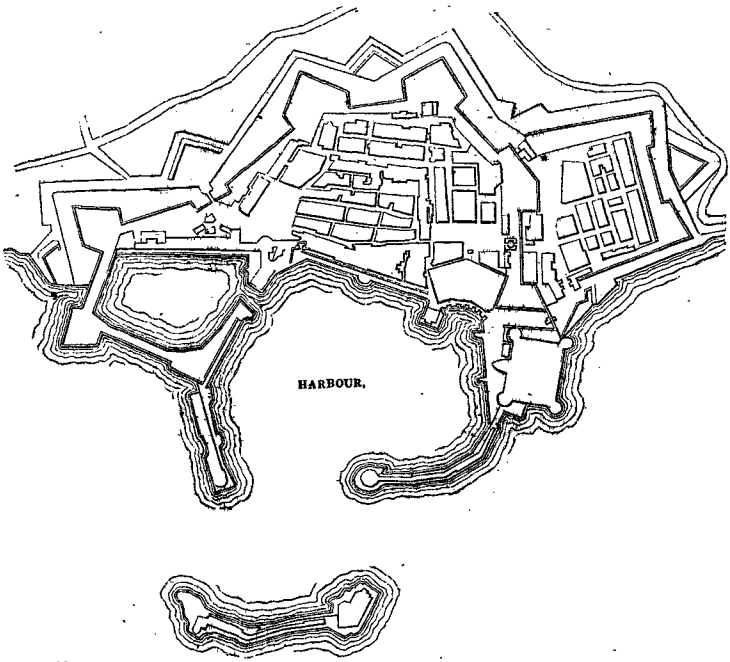


Fig. 146. CIVITA VECCHIA.

All these ports have long become useless, and the modern one of *Civita Vecchia*, which is now at the mouth of the Tiber, is forty miles from Rome, and fourteen leagues distant from Ostia; it was the ancient Centocellæ, so called from its having an hundred arcades, to which as many vessels could be moored.

The Roman ships were called *Triremis*, *Quadriremis*, and *Quinqueremis*, as they exceeded each other by a bank of oars: there were vessels still larger, as the *hexeres*, the *hepteres*, the *octeres*, &c.; and the ship Philopater, Plutarch informs us, had forty banks of oars; three banks of oars were raised in a sloping direction one above the other, consequently those with the greatest number were the most lofty vessels; when in port they were placed often under arcades, and protected from the weather, as we see represented in an ancient picture.

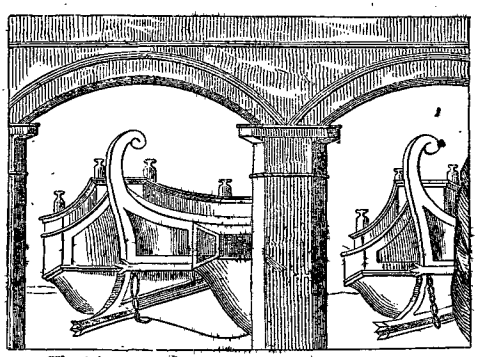


Fig. 147. ARCADES AT OSTIA.

Terracina. The size of this port and the walls which surround it show that its establishment was calculated for commerce, as well as for the protection of a numerous navy. Two straight sides united by a gentle curve form this harbour, the entrance to which is 367 feet in width; the length of the other three sides, or its perimeter, is 3705 feet. Its greatest diameter is 1319 feet, and the least, which is perpendicular to the pass on the land side, is 1247 feet. Its total area is estimated at 128,107 square yards. Near the right bank of the port is an accumulation of earth, called Monte Cello, collected from the frequent cleansing. The canal, which now communicates with the port, and which brings down the waters from the Pontine marshes, enters through a breach made in a rectilinear part of the enclosure. The wind, which blows directly into the mouth of the harbour, is the north-east, but its force is destroyed by the heights of Pisco Montano, on which, probably, was

placed the pharos, and by a projection of the shore into the sea, forming a small cape, comprised between the Pisco Montano and the Torre Gregoriano; from the latter point to the extremity of the port, the slope of the shore is from north-west to south-east. The external part of the wall of this enclosure has a considerable talus; the ancient rocks still remain at its base. The facing on the internal part is perpendicular, and holes in marble blocks remain, through which the cables were passed when the vessels were moored.

The mole, which forms the enclosure, was raised 12 feet in height above low water; its width at the top is 40 feet, and there are few works more substantial or solid to be met with.

Some remains of columns and their entablature lie at the foot of the mole, and in all probability they once adorned a structure on the platform which was the residence of the officers of the port. The foundation or establishment of these works are of great antiquity, and are said to be the first regular constructions of this kind in Italy. In many parts the opus reticulatum may be seen: we know that it was restored by Antoninus Pius.

Adria, whence the Adriatic derived its name, was the ancient Atria; it is 32,000 metres from the sea; Rimini is 1500, and Ravenna 8000. At Rimini terminated the two great roads, the Emilian and the Flaminian; here was a triumphal arch and a bridge, which were erected in the time of Augustus. A canal conducts small craft from this once famous port to the sea.

A variety of methods was employed in the construction of double dams, formed of piles and planks, chained or tied together, and filled in with clay and marsh weeds, well rammed in or puddled, to keep out the water. When this was effected, the water was pumped out by the various machines then in use, and which were most effective for the purpose. The Archimedean screw and water wheels were employed, after which the foundations were dragged or dug out; when, if soft, alder, olive, or oak piles, previously charred, were driven in, and the intervals between their heads filled with charcoal or some other equally imperishable material. On this, walls of squared stone, in regular courses, were laid, taking care that the longest were employed as bond-stones, to pass into the thickness of the wall, and thus tie in the others. The inside of the wall was then filled with rubble or masonry, and on such work, towers were built. The arsenals around a port usually had a northern aspect, the heat being supposed to encourage the teredinos and other destructive worms, and they were generally constructed of a material not likely to take fire. These buildings were for the purpose of receiving the largest ships, which were drawn on shore, and protected under them.

Naples is in 40° 50′ north latitude, and 14° 14′ east longitude; this city is of Grecian origin. Livy mentions it as joining with the inhabitants of Palæpolis and the Samnites

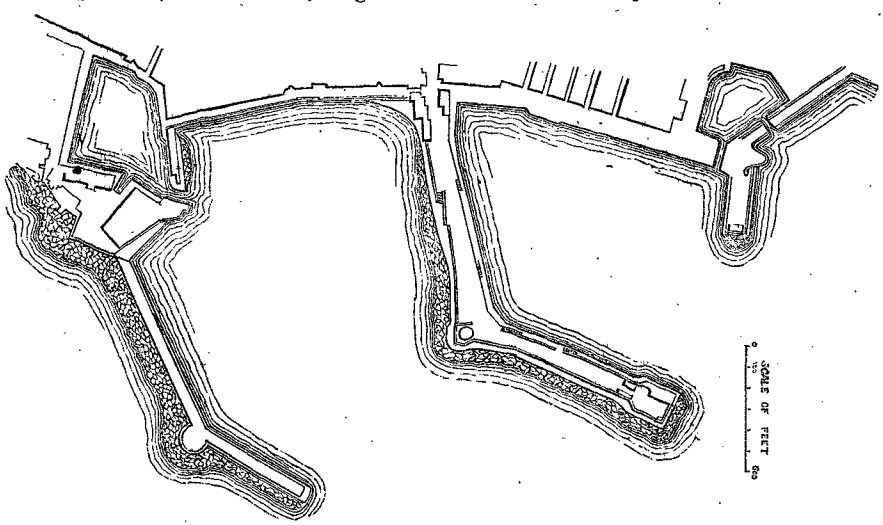


Fig. 148. NAPLES.

against the Roman power. It is situated in the bosom of a capacious bay, and the harbour is formed by a mole, built in two directions, having its lighthouse at the bend. Within the mole, the ground is soft, being covered with three or four fathoms of water. This city, from the number of its inhabitants and its beauty, has been styled the Queen of the

Mediterranean. Its position is in the form of an amphitheatre on the shores of a bay, shut in by the Isle of Caprea, 17 miles distant to the south, and Procida and Ischia.

Vesuvius on the east may be seen, lifting its fire-scathed summit above the villages of Portici and Torre del Greco, and on the other side is the grotto of Posilippo. The atmosphere is usually bright and cloudless, and it was made by the wealthy Romans a most delightful place of residence, the shores of its picturesque bay being covered with their villas.

On our way from Naples to Pozzuoli, we find, on approaching the latter place, lofty and precipitous cliffs of indurated tuff, between which and the sea lies a low level tract of fertile land. This cliff, now far inland, may be seen opposite the island of Nisida, two miles and a half south-east of Pozzuoli: pursuing our course northwards, we find the sloping sides of Monte Barbaro, terminating also in an inland cliff, which indicates that the sea once washed its base. Great has been the change to which this coast has been subjected; and we have every evidence that the land has been both depressed and upheaved several times: the firm earth and the inconstant sea have frequently changed their relative positions. The physical causes now in operation, as formerly, enable us to account for the situation of cliffs where the sea has now retired, and for estuaries, where high tides once rose, being silted up, and rendered dry land. The volcano and the earthquake on these shores have effected, in the memory of history, wonderful changes: both, no doubt, have a common origin; and they continue occasionally to shake the whole district around Vesuvius, to alter the current and quality of the waters, and the character of the mineral substances that come within their effects. In this neighbourhood is found the earth *puzzolana*, so valuable to us as an hydraulic mortar, and which the ancients made so much use of in the formation of their moles and breakwaters; they had only to cast it into the sea, between proper limits, and an island was at once formed.

Cuma, Miseno, Baiæ, and Pozzuoli. These ports were at one time celebrated for their commerce with the greater part of the habitable globe. Capua, one of the noblest and most splendid cities of the Romans, surrounded by plains of great beauty and fertility, was supplied with its merchandise and luxuries from the vessels which resorted to its coast.

Strabo, lib. v. cap. 4. mentions Cuma as a very ancient city, which, with its amphitheatre was situated, at N, on a rock overlooking the sea. Miseno occupied the promontory at M,

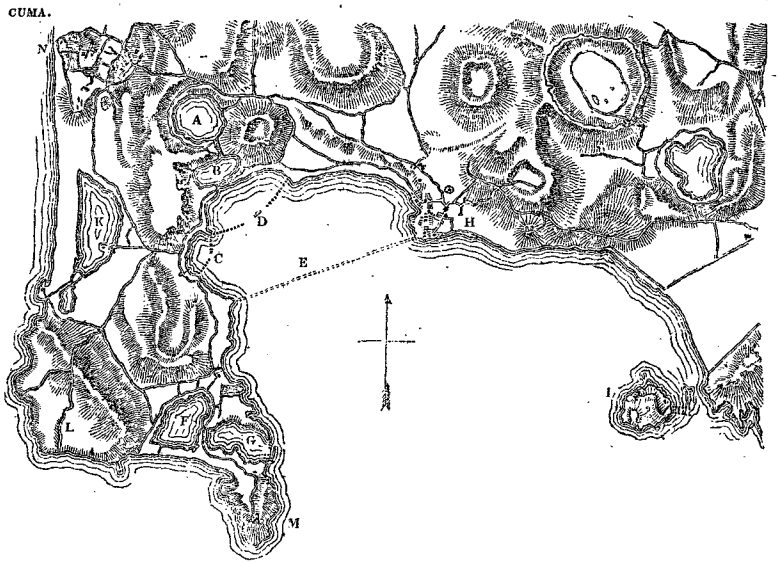


Fig. 149. CUMA, MISENO, BAIÆ, AND POZZUOLI.

and its port, which was double, F and G. The town and basin of Baiæ are shown at C, whilst Pozzuoli stood on the outside of the bay, at H, and was joined to the castle at Baiæ by the celebrated bridge, E, of Caligula. The lake Avernus, at A, communicated with another port at Lucrinus, B, or Porto Guilio. The island of Nisida, at I, detached from the main land, bounded the eastern part of this beautiful bay. Behind the promontory of Miseno, I,

lay a large lake, K, called Acherusia, which communicated by means of a canal with the seas on the western coast.

Cumæ was founded by a colony of Greeks from Chalcis in Eubœa and from Cumæ in Eolis: although it was the first Grecian establishment in Italy, for many centuries it was the chief in power, opulence, and population. Its peculiar situation fitted it for commerce, and its oracle, sibyl, and temple, brought to it many votaries and visitors. When Juvenal wrote, the neighbouring towns of Baiæ and Puteoli or Puzzuoli were preferred on account of their salubrity to the marshy district around Cumæ; soon afterwards its population declined, and in the sixth century we read of it as a mere military post. The ruins of the ancient city may yet be traced, in a solitary wood, which has grown up over its once busy streets, where the wild boar is now sought and destroyed by the hunters, this district forming part of the royal chase belonging to the king of Naples.

The Lake Fusaro, or the ancient Acherusia palus, situated on the south towards Misenus, is a long and shallow piece of water, called by Strabo a muddy irruption of the sea; there is a small island with the remains of a castle, and at the end of the lake is a pool, called l'Aqua Morta.

Baiæ has a bay, in the form of an amphitheatre, and is situated on the western coast opposite to Pozzuoli, from whence it is about three miles distant; ruins of Roman villas, baths and temples, may be seen at the bottom of the sea, which indicate a much larger extent at one period. Here the emperor Nero had a palace and splendid baths, which Suetonius tells us contained a reservoir, in which the thermal waters of the surrounding district were collected. Nero had intended that his palace should have extended over the whole country lying between Lake Avernus and Misenus, a distance of at least three miles and a half.

Portus Julius was formed by Augustus, for draining the Lake Avernus, and to admit the waters of the ocean for the purpose of dispelling the noxious vapours that constantly hung over the Infernal Basin. When this work was undertaken, the anger of the gods or infernal divinities was supposed to be raised, and a violent tempest accompanied the descent of the waters of the lake into the ocean, which was probably no more than the effect of removing the barrier of earth which confined them, and kept them from flowing into a lower level. After the waters had passed through the new port, the Lake Avernus was stripped of its horrors; on the margin are many ruins; near the shore may be traced those of an extensive mole, that appears to have formed an outer port, and may be a portion of the harbour of Agrippa, mentioned both by Virgil and Horace.

The Lakes Avernus and Lucrinus being united, formed a most capacious harbour, and beyond is pointed out some remains of a mole, now crossed by a road, said to have been constructed by Hercules.

The Lucrine Lake is covered with rushes; the bottom was uplifted in the year 1538, and now forms a conical hill, instead of deep water as formerly.

The Lake Avernus is about 1½ miles in circuit, surrounded by gardens and woods, and bears no resemblance to the description left us by the poets.

Pozzuoli or Puteoli, a town of Greek origin, first called Dicæarchia, was erected by the early settlers at Cumæ; the Romans strongly fortified it about two centuries before the Christian era, and made it a port of considerable importance. Its site, in the centre of a fine bay, surrounded by lofty coasts, watered by rivers, cannot be surpassed for a commercial port.

The Romans here purchased all that an extensive commerce with the east could procure for them: it was injured by the earthquakes to which it was subject. In one of its squares there still remains a pedestal in marble, on which is represented in bas-relief the fourteen cities of Asia Minor, which were rebuilt by Tiberius after their destruction by an earthquake. Behind the city, to the north-east, are the remains of its amphitheatre, and near the coast, on the western side, those of the temple of Jupiter Serapis, near which are the ruins of the famous mole that formed the port. Several of its piers remain sunk in deep water, which supported the open arches, said to have formed a part of Caligula's celebrated bridge, which extended from the port of Puteoli to Baiæ. But little reliance can be placed on this statement, as in all probability the mad scheme of this emperor was nothing more than a floating raft or bridge of boats, carried across the bay, in imitation of that constructed by Xerxes. Seneca, Ep. 77. speaks of this mole or pilæ, and Strabo designates it as a work carried out far into the sea, at which vessels of considerable burthen might with great convenience discharge their cargoes.

Antoninus restored this splendid mole after it had received some damage; it had been probably built long before, in the manner commonly practised by the Romans. It deserves our attention, both for the economy evinced in the quantity of material employed, and for the means it afforded of allowing a free current for the waters, consequently diminishing the chance of the bay silting up. The great strength of this work, exposed at times to a heavy sea, mainly depended upon the fine cement obtained on this coast, which when used under water acquires the consistency and strength of marble.

In a picture found at Pompeii is the representation of one of these open moles with seven arches, which allow the sea to pass freely under them; the upper part or road is

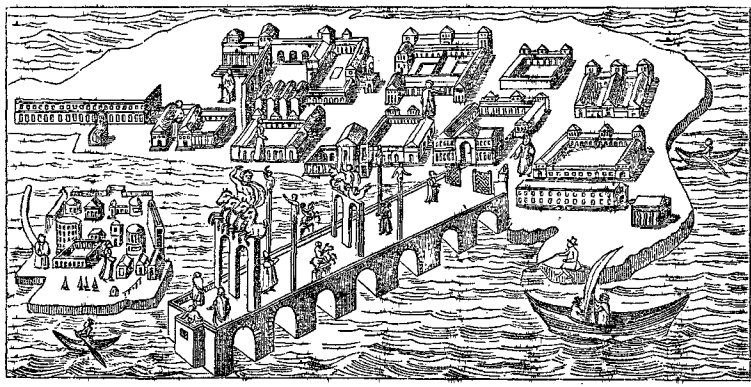


Fig. 150. ANCIENT PORT.

decorated with trophies. There is also shown an island with various buildings constructed on it, probably for the purpose of containing the stores required in the equipment of vessels, or for the residence of the guardians of the port.

At the end of the fifteen arches of the mole at Pozzuoli was the lighthouse, of which there are now no remains. In setting out the openings or piers which sustained the arches, their span was made equal to their depth, the piers being in width half as much more as that of the apertures; thus great strength was obtained, and the force of the waves beating against such a structure would lose a part of their power, being allowed a passage through to the other side.

The section through one of the arches of this mole exhibits the portion towards the sea, and by the side is shown the level at which the water usually stood with reference to the arches, which were not semicircular.

The great distance that some of these open moles were continued into the sea, where there was a considerable depth of water, would lead us to imagine

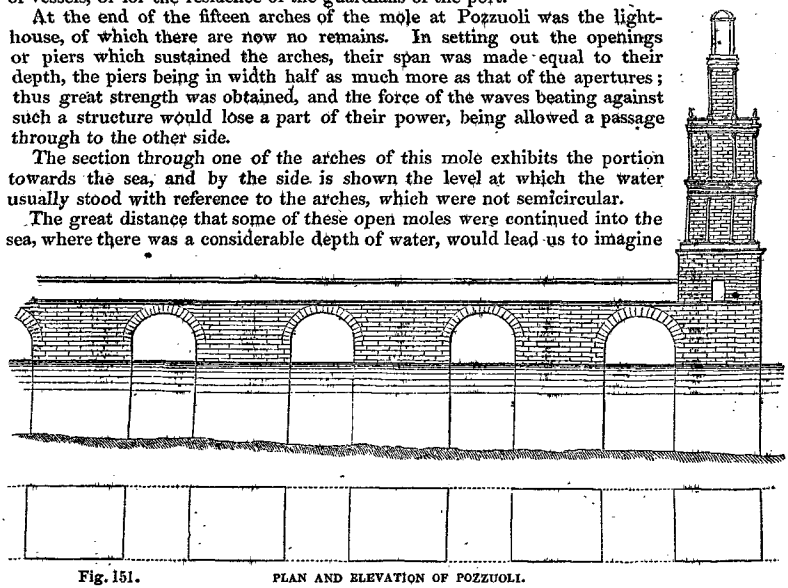


Fig. 151. PLAN AND ELEVATION OF POZZUOLI.

that the piers could not have been constructed without the aid of very strong cofferdams; and we learn that such were used resembling ships, and sunk where the work was to be executed. There can be no doubt that the Roman engineers were accustomed to drive piles in deep water, as the descriptions left us of Cæsar's and Trajan's bridges fully prove: to unite these piles as a barrier against the sea, and afterwards pump out the water by the machines in use, would not be a difficult task: the tide in the Mediterranean does not rise sufficiently to interrupt the progress of such undertakings, and where the faces of the piers are worked in regular courses of masonry, no other method could have been adopted: by heightening the sides of one of their large galleys, a carpoon might be formed, in which they could pile up their material, and thus effect their object.

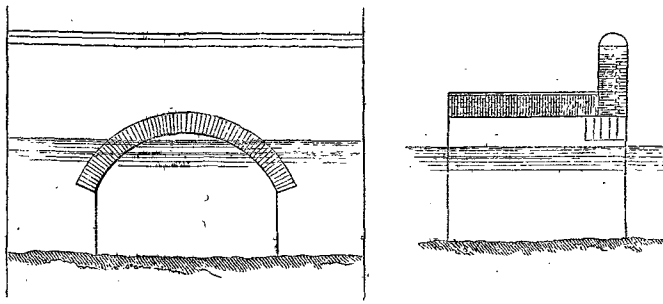


Fig. 152. MOLE. SECTION.

The Island of Nisidà, or Nesis, is situated at a small distance from the eastern promontory, and on it is now placed the modern lazaretto to the Bay of Naples.

Misenus with its port occupied the opposite promontory or the western side of the bay; among the ruins may be traced many hollows in the rock, which probably served as docks for shipbuilding. The double port of Misenus had but one entrance, guarded by a mole, in the usual manner of the Roman ports. Near this part of the coast stood the mansion of Lucullus, afterwards occupied by Tiberius: the poet Phœdrus observes, "that from its summit might be seen the shores of Sicily." Pliny the younger and his mother resided here, near the sea, their house being separated from the water only by a small court.

The Piscina mirabile, a vaulted edifice, divided by four rows of arcades, and situated near the port, is supposed to have formed part of the great reservoirs constructed to retain fresh water for the vessels that entered the harbour of Misenus, which lies immediately under the hill on which it is constructed, and, according to Suetonius, it was one of the works commenced by Nero. He alludes to it in the following quotation: "Inchoabat piscinam a Miseno ad Avernum lacum, contectam; porticibus conclusam, quo quidquid totis Baiis calidarum esset converteretur."

The port of Misenus is protected by high lands on all sides, and its small haven is always in a tranquil state: Augustus made it capable of retaining all his fleet. It is separated from the Mare Morto by a narrow neck of land, through which was cut a canal, crossed by a bridge, without interrupting the navigation into the inner port thus formed. The mountains of Procida and Selvaggi afford a shelter from the north: along the shores extend the famous Elysian fields.

The mole at Misenus is a fine example of another system practised by the Romans; a double range of arches is so set out, that the piers of one line are placed directly opposite the opening of the others. The force of the waves and currents were by this arrangement broken; at the same time there was no chance of any deposit being made between the piers, or within the mole; and no method can be more economical or judicious.

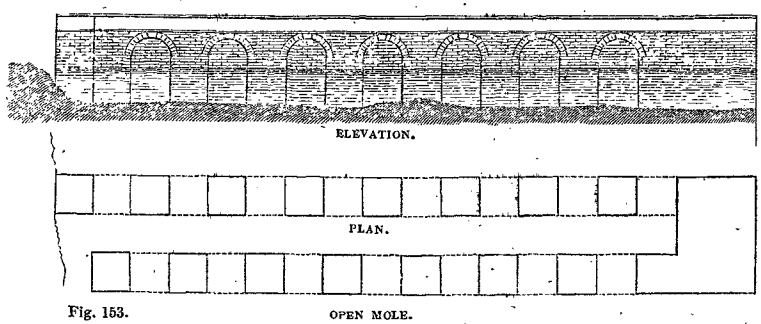


Fig. 153. OPEN MOLE.

Leghorn, in latitude 43° 35′ north, and longitude 10° 16′ east, is a considerable sea-port belonging to Tuscany. Its outer harbour is defended by a fine mole, half a mile in length, thrown out in a north-north-west direction; and within the outer is an inner harbour, with a depth of 8 feet water.

In the outer harbour the rise of the tides is estimated at 14 inches, and at the end of the mole there is a depth of water of upwards of 18 feet.

South-west of the mole, on a rock, is constructed the lighthouse, which exhibits its light at a height of 170 feet above the level of the sea.

This port was the ancient Livorno, Liburni portus, or Liburnum, and is situated opposite the small island of Malora. The town is nearly square, and about 13,000 feet in circuit; the mole is a favourite promenade, and from it may be seen the islands of Gorgona, Capraia, and Corsica. The ships are moored beyond the mole, attached to large iron rings.

There are three lazarettos, an arsenal, and extensive warehouses.

The Bay of Spezzia, or Sinus Lunensis. This bay is one of the most magnificent in Europe, and has a spring of fresh water in the centre; it is encircled by lofty mountains; the Apennines approach the sea, towards Carrara, and adjoin the Alps beyond Genoa.

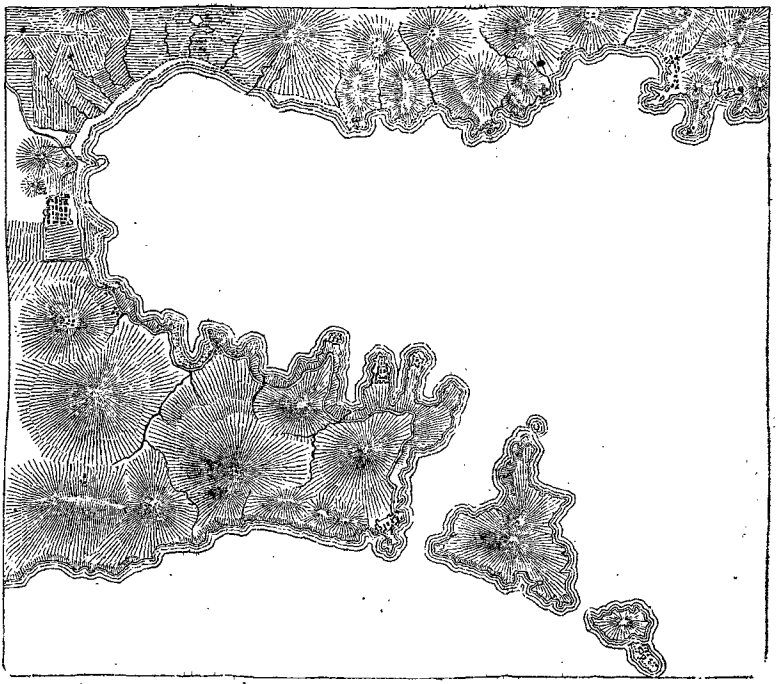


Fig. 154. BAY OF SPEZZIA.

The ancient town of Luna, now called l'Erice, takes its name from Erycis Portus: the beauty of the bay and the marble quarries in the neighbourhood are often described by the Latin poets. Pliny, in his thirty-sixth book, giving an account of the various marbles then in use, enumerates some of a white and sparkling quality, then recently quarried about Luna. This marble was called lychnite, in consequence, Varro says, of sparkling in the lamplight when hewed out of the quarry. At a later period, vast quantities of Luna marble were shipped from this port, and the temples and other public buildings at Rome were built with it.

From the rising ground around this port, Strabo, lib. v. cap. 3. informs us that the island of Sardignia might be distinctly seen.

Genoa has a splendid harbour, formed artificially, by the construction of two moles; that on the east side, called the old, projecting from the centre of the city, is 260 fathoms in length; its direction is west by south, and near the middle is constructed a modern battery. The new mole, on the opposite side of the port, projects from the shore 210 fathoms in an east-south-east direction. The opening between these two moles, which allows of the passage of ships into the harbour, is in width 350 fathoms. The harbour is in form a half amphitheatre, its diameter being nearly 8000 fathoms; there are no difficulties to encounter on entering it; and there is a good depth of water near the new mole, where men of war and larger vessels may anchor at a little distance from the shore.

Within the outer harbour are two smaller, for galleys and merchant ships used by the coasting trade.

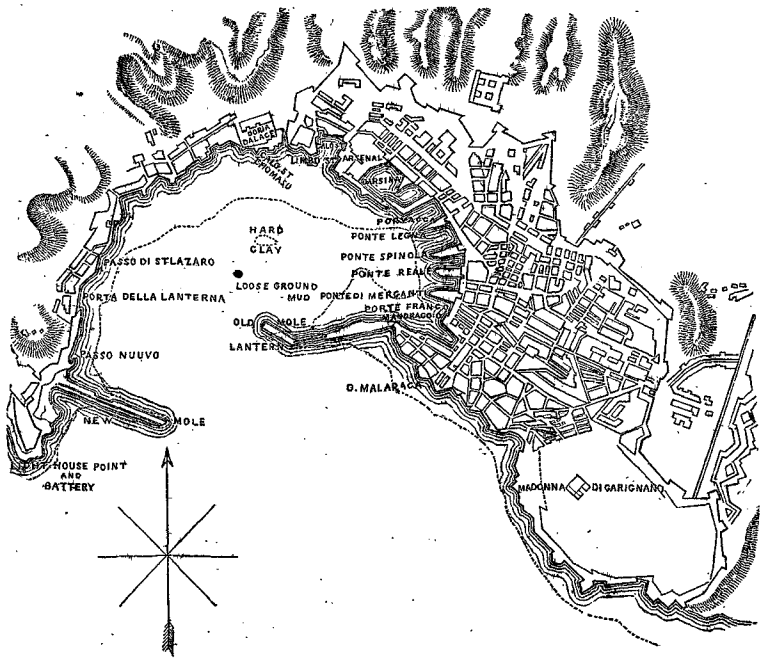


Fig. 155. GENOA.

On the west side, without the harbour, on an extreme point of land, is the lighthouse, a square building of many stories, based upon a rock, which may be seen at sea for many miles.

The latitude of Genoa is 44° 45′ north, and the longitude 8° 50′ east, and its situation is on the northern shores of the Mediterranean; the town is about 6 miles in circumference, inclosed in a double rampart. By Strabo it was called the Emporium Totius Liguriæ: it was at a very early time the chief city of the Ligurians; commerce then, as in the latter period of its history, was always the favourite pursuit of its inhabitants; the nobles in the middle ages were both its merchants and defenders, and in the twelfth century they sent out a fleet consisting of twenty-eight galleys and six other vessels to assist in taking Cesarea.

Venice, in north latitude 45° 25′, and in east longitude 12° 20′, is on the north-eastern coast of Italy: it may be reckoned one of the earliest as well as the most considerable commercial cities of modern Europe, having been established soon after Attila invaded Italy, in the year 452. It is built upon a number of small islands, near the northern extremity of the Adriatic Sea, or Gulph of Venice, and separated from the main land by a marshy lake, about five miles in breadth and covered with water to the depth of 3 feet. A canal, 1200 yards in length, and about 100 feet in breadth, separates the city into two nearly equal divisions; from this branch off many other canals, which are crossed by upwards of 500 bridges, most of them constructed of stone, and some of great beauty. The inhabitants pass from house to house in gondolas or small boats, and the merchandise is landed at once from the barge to the doorways of the warehouses. The Venetian ships of the largest dimensions were called galeasses or argosies, some of which carried crews of 600 men, and mounted 50 pieces of cannon; they must have entered many of the ports of England at a very early period, for we find from our own records, that in the year 1325 they had a charter, and full liberty to discharge their cargoes, and return in safety. There was a magnificent arsenal situated near the eastern end of the city, defended by a rampart; and before the entrance were the two lions in granite that once adorned the Piræus at Athens.

The houses are constructed both of brick and stone, and their foundations formed upon piles; many are more than four stories in height. The bell tower or campanile is the

loftiest of the public buildings, its height being above 300 feet, and it does not exhibit any settlement.

Ancona was founded by a colony from Syracuse, which settled there about 400 years before Christ, and the Romans constituted it one of their principal naval stations on the shores of the Adriatic.

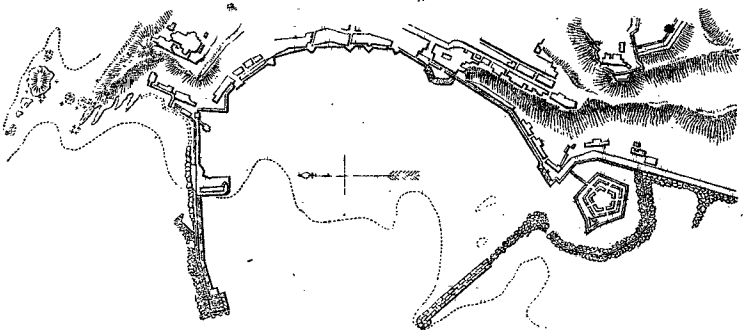


Fig. 156. ANCONA.

The emperor Trajan constructed the splendid mole which now remains, as well as the fine triumphal arch which adorns it.

The mole, a solid mass of masonry, rises to a considerable height above the sea; the stones that compose it are large, and cramped together firmly with iron; below it is another mole with a triumphal arch, the work of Vanvitelli. At the extremity is the lighthouse, all solidly constructed, and equally creditable to him as a civil engineer, as is the arrangement of the lazaretto.

Antium was once a considerable port, the capital of the Volsci; it was greatly improved in the time of Nero, and much resorted to by the opulent Romans, who had villas in the neighbourhood. The road to it runs along the Alban hills, over the Campagna, and then through a forest which for many miles borders the sea coast.

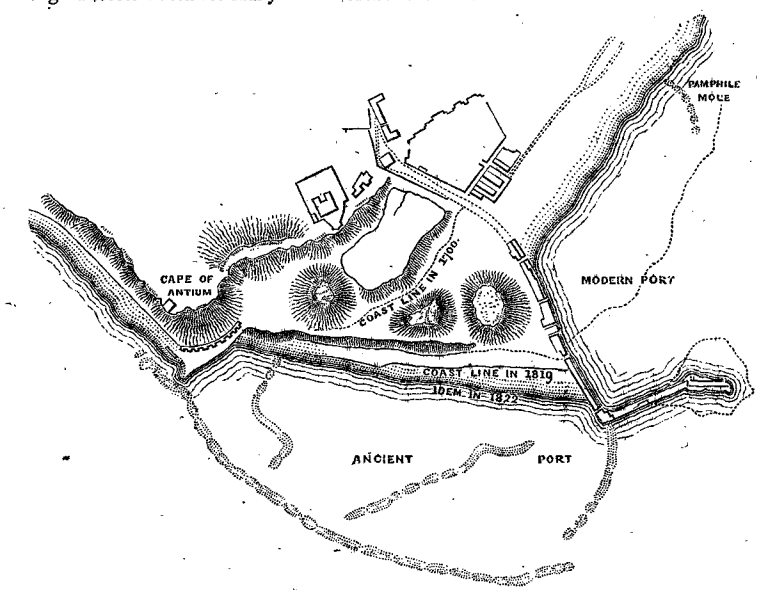


Fig. 157. PRESENT STATE OF ANTIUM.

The town of *Meltuno* may be the remains of this once famed port, which had two moles stretching out into the sea, with a narrow entrance between; at the mouth was an artificial

island, on which was erected the pharos. At the extremity of each of the moles was a tower, in which was placed the machinery for extending a chain across the opening.

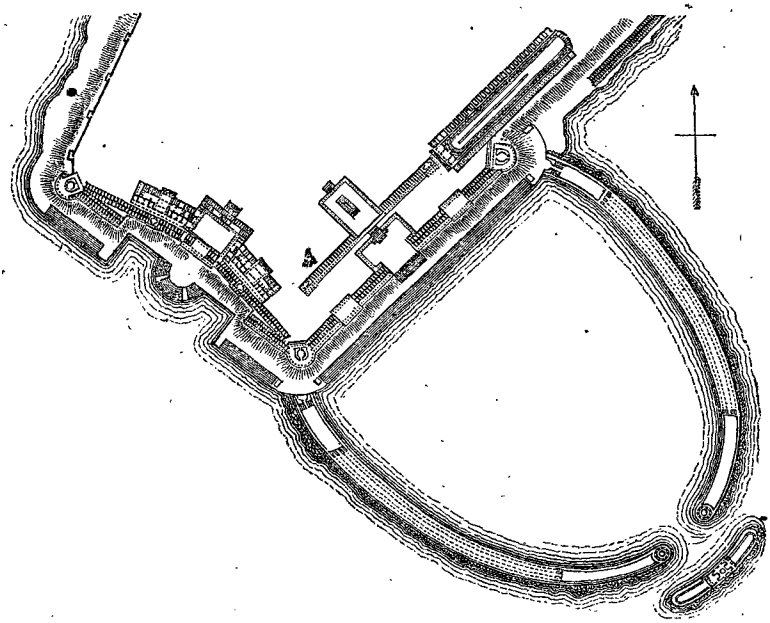


Fig. 158. NERO'S PORT AT ANTIUM.

Tarentum consists of two ports, the outer called Mare Grande, the inner Mare Piccoli. A bridge of seven arches unites the present city to the continent on the north side, through

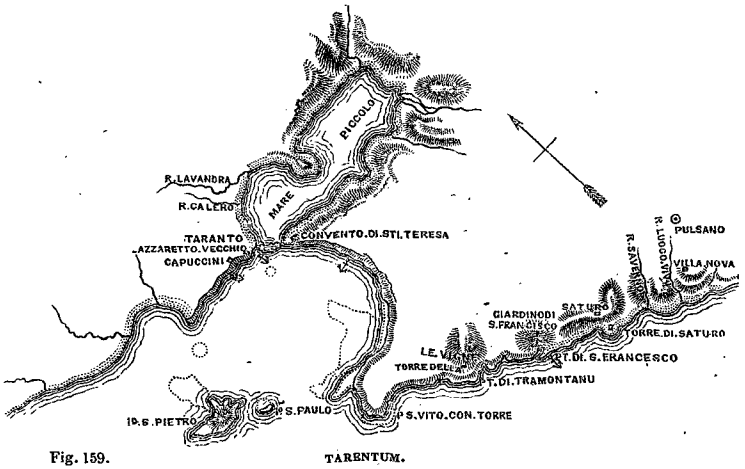


Fig. 159. TARENTUM.

which the sea flows with great impetuosity; this formerly was the entrance into the harbour, which will now only admit small boats. In the time of the Romans there were drawbridges, to enable the military in the citadel to command the inner port. The enemy's fleet in the second Punic war was so completely blocked up within it, that it could not regain the sea.

Between the arches of the bridge was a wooden frame, to which nets were attached for

catching fish, and the aqueduct that still supplies the town passes over it; it was built about 1543. The water is brought from the mountains of Martina, a distance of 14 miles, where, after being collected into reservoirs, it was led under ground to deep cisterns at Tremiti. At La Follia it pursues an open course for 7 miles, then passes an aqueduct constructed over 203 arches, then through channelled stones fitted one into the other.

Tarentum has preserved but little of its Grecian foundation, and none of the ancient walls that enclosed it; fragments of Etruscan vases have been discovered in all directions. Of the temples, gymnasia, theatres, and other splendid monuments, nothing now remains, not so much as a single column, to tell us where the city stood.

The moles which protected and shut in these ports were constructed with massive masonry, and with piers and open arches. That portion which was solid was carried out progressively, until the arms were completed; these arms were called left and right, and are described by Suetonius as well as Pliny, in their accounts of the ports of Ostia and Centocelli. That part between the ends of the two moles was called the mouth, and that between the island and the moles the jaws or fauces.

Brundusium. — Though there is now but little remaining of this once extensive city, the port, which is double, was reckoned one of the finest in the Adriatic Sea. The outer was formed by two promontories, which as they advance leave a narrow channel between them. At the mouth lies an island now called St. Andrew's, which secures the whole from the violence of the sea. At the bottom of the bay the hills recede in a circle, and form the

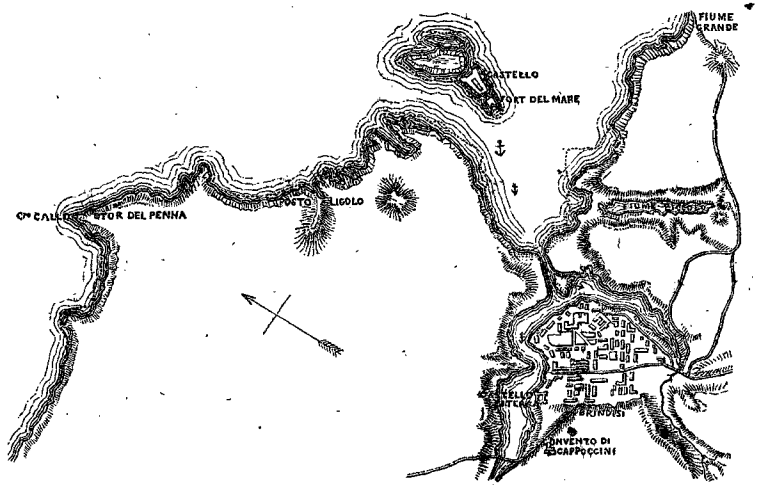


Fig. 160. BRUNDUSIUM.

inner harbour, which is 2½ miles in length, and 1200 feet in breadth, encompassing a great part of the city, which has somewhat the form of a stag's head and horns; in the old Messapian language, the head of a deer being called brundusium.

There is a fine soil, depth of water, and safe anchorage; and the destruction of this place as a port may be partly owing to the silting up of the channel between the two havens, which was probably caused when Cæsar attempted to block up Pompey's fleet, by driving piles into the neck of land between the two ridges of hills, and throwing in earth, trees, and ruins of houses. When Don Vito Caravelli was employed, at the latter end of the last century, to improve this port, in deepening the channel, he found several medals, and had many of the piles which were driven in by Cæsar drawn up: they were small oaks stripped of their bark, and at that time quite sound.

Cæsar's description of what he did at Brundusium on this occasion is interesting: he states, as the work could not be carried quite across the port, in consequence of the sea's depth, he prepared double floats of timber, 30 feet square, which were secured by an anchor at each corner; these extended to two moles, which he threw up, one on each side the haven, where the entrance was the narrowest and the water shallow. After the rafts were securely moored, he covered them with earth and fascines, and made them sufficiently strong for his legions to pass over with ease, and also have firm footing to defend them. The fronts and sides of these rafts were protected by parapets or hurdles, and every fourth float had a tower of four stories constructed on it, the better to guard the work from fire, and protect it from the boats which might be sent against it.

Pompey made use of several ships which were in the port, and fitted upon them towers of three stories in height, which he filled with engines and darts, and then sent them down to break through the floats which Cæsar had contrived, and destroy his works; in this, however, he did not succeed; but before Cæsar had quite completed his blockade, Pompey found means to embark on board his ships and effect his escape.

Roads.—The immense extent of roads constructed by the Romans, their duration and stability, the obstacles which they surmounted in carrying them over marshes, lakes, and mountains, have, in all ages, excited astonishment and admiration. Twenty-nine great military roads centred in Rome, some of which were carried to the extreme points of the vast empire. For fifty miles' distance from the capitol, each side was decorated with temples, baths, hippodromes, tombs, and superb edifices. Buildings used for lodging-houses and for changing horses were erected at the public cost, at regular distances; and at these several posts, were maintained relays of horses for the couriers, as well as mules, asses, oxen, and carriages for the transport of the materials for the army, and mansiones for the lodging of the soldiers were constructed at distances from 30 to 36 miles.

The whole Roman empire comprised eleven regions, viz. Italy, Spain, Gaul, British Isles, Illyria, Thrace, Asia Minor, Pontus, the East, Egypt, and Africa, and these were divided into 113 provinces, traversed by 372 great roads, which, according to the Itinerary of Antoninus, were together in length 52,964 Roman miles.

Under the kings there were no paved roads, and the first seems to have been commenced by Appius Claudius, about 442 years after the founding of Rome, whilst he held the office of censor; this was not only the earliest but the best constructed; and Statius the poet designates it as the Queen of Roads in his time. Appius Claudius was honoured with the highest offices which the republic could bestow; he was censor, twice consul, prætor, curule edile, and lastly dictator, when he conquered the Sabines, and obtained several victories over them and the Etruscans; after which he erected the temple of Bellona.

The celebrated road, or Appian Way, is mentioned in a variety of inscriptions, and by most of the ancient authors: Procopius, in his "de Bello Gothico," says that its length was so great that it could not be passed by a traveller going at a swift pace in less than five days; that its breadth was sufficient to allow two chariots to pass without inconvenience, and that it was paved with large blocks of stone, brought from distant quarries, dressed and squared with the chisel, and joined very exactly without the aid of metal or any other material; the work was so perfect, that it seemed as if nature had performed it rather than man, for the very joints were hardly perceptible. Whether the whole way from Rome to Brundusium was executed by Appius is doubtful, and it is less certain that it was paved by him the whole length; the probability is, that his way terminated at Capua.

Strabo, describing Terracina as situated near the shore of the Tyrrhenian Sea, proves that the paved Appian Way approached it, and Horace, in his Journey to Brundusium, describes it as paved throughout.

The road from Capua to Brundusium is longer than the portion from Rome to Capua, and the whole was, according to Strabo, 360 miles in length: that Appius Claudius only conducted it to Capua, a distance of about 142 Italian miles, is most probable, as in his time the provinces beyond were not under the dominion of the Romans. It is difficult to say at what time the latter portion of the work was completed, which it evidently was before the time of Augustus. Plutarch observes that Julius Cæsar was appointed commissary of the Appian Way, and that he expended large sums of money upon it, and to him probably may be attributed its termination.

Quitting Rome the first station on the Appian Way was distant sixteen miles, at Ariciam; from thence seventeen miles to Tres Taburnæ; eighteen miles to Appii Forum; eighteen miles to Terracina; sixteen miles to Fundi; thirteen miles to Formiæ; nine miles to Minturnæ; nine miles to Sinuessa, and twenty-six to Capua; in all 142 miles: and this is the distance Procopius imagines could be accomplished in five days by an expeditious traveller.

From Capua to Equotuticum, "ubi campania limitum habet," was a distance of fifty-three miles, viz. to Caudium twenty-one miles; Beneventum eleven miles, and Equotuticum twenty-one miles.

From Equotuticum to Hydruntum, where they embarked, was another 235 miles; viz. to Eeas eighteen miles; to Erdonias nineteen miles; Canusium twenty-six miles; Rubas twenty-three miles; Bruduntum eleven miles; Barium twelve miles; Turres twenty-one miles; Egnatiam sixteen miles; Speluncas twenty miles; Brundusium nineteen miles; Lupias twenty-five miles; and Hydruntum twenty-five miles.

The Domitian Way commenced at Sinuessa, and branched out of the Appian Way, continuing its course along the sea-shore, crossing the rivers Savo and Volturnus, skirting Mount Gaunus, and Massicus, fertile in wine; continuing its direction through the marshes of Linturna, and between the Lakes Avernus and Acherusia, passing by Cumæ, terminated at Pozzuoli.

Strabo, in speaking of these three excellent roads, places first the Appian, which he

describes as far as Sinuessa; Dion carries it beyond: and afterwards says that it united the seven hills of Rome with Baiæ.

The Domitian Way, though of no very great extent, was of the greatest use, as it enabled travellers to pass marshes and quicksands, by means of bridges and causeways constructed at a vast expense. In many portions masses of concrete were thrown into swampy places, and the distances formerly passed greatly shortened. All the long detours were avoided, and Statius tells us that a triumphal arch was raised to Domitian by the senate and Roman people, in gratitude for the benefits bestowed upon them by this work.

The public roads, among the works of Roman magnificence, ranked preeminently high; vast labour and expense were bestowed upon them, and their construction, as we now behold them, seems to have been intended to outlast their empire. Such arteries, as they were termed, which conducted to the heart of the imperial city, were not thought unworthy of the attention of the greatest men of the republic; none but those of the highest rank were even eligible to the office of superintending them, and during the empire Augustus himself took charge of them. The Romans, however, notwithstanding the goodness of their roads, were not very fast travellers, for Augustus, when he went to Præneste, a distance of only twenty-five miles, usually halted for the night about half-way. And Horace tells us that he performed his journey to Brundusium, which was distant about forty-three miles, in the same time, but he observes that an expeditious traveller could perform the journey in a day.

Among the Romans the various roads were distinguished by the names *Via, Actus, Iter, Semita, Trames, Diverticulum, Divertium, Callais,* &c.

Via, answers to our common roads; its breadth was 8 Roman feet, so that carriages could pass without collision.

Actus, was a road for the passage of a single carriage; it derived its name from a measure used in surveying land, of which the breadth was 4 feet, and the length 120.

Iter, was a road for pedestrians and horsemen, the breadth of which was 3 feet.

Semita, was only half the breadth of the Iter, and when it crossed fields it was called Trames, Diverticulum, and Divertium.

Callais, was a road through mountainous districts, for the purpose of attending the flocks.

These roads, peculiarly adapted for civil purposes, united with other great lines, which traversed the numerous provinces of the empire, which were called military, consular, or prætorian, or were named after the consuls and emperors who had constructed them, as the Appian, Flaminian, and Domitian; they were sometimes designated

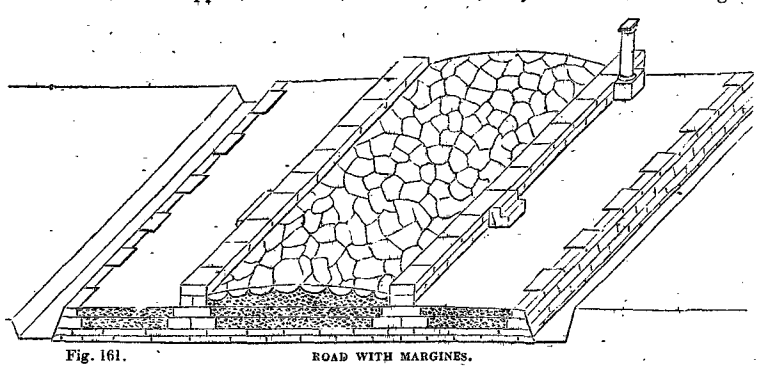


Fig. 161. ROAD WITH MARGINES.

by the names of the provinces, as the Latian, Tiburtine, Campanian, and Prænestine ways. The great military roads were divided into three distinct parts; that in the middle was the most elevated, and called agger, and had a convex form or curve; this was usually paved with large stones of various shapes.

Most of the roads in the neighbourhood of Rome, as the Appian, Latian, Labicum, Tiburtine, and the Prænestine, had the paved part 16 Roman feet in width, or 15 feet 6 inches English; this portion was separated from the two sides, called margines, by a curb, 2 feet wide and 18 inches high, which served as seats for travellers.

The middle portion was destined for the infantry, and the margines for horses and carriages: the breadth of each margin was half that of the road in the middle, so that the entire breadth of these military ways was from 36 to 40 Roman feet.

The streets in the towns were sometimes called Via Militaris, as were the chief of those in Rome, which were the commencement of the great roads; under these were constructed

vast sewers, which, according to Pliny, ranked among the greatest works ever undertaken. The subterranean fosses, or continued bridges of great length and breadth, sustained enormous weights, as columns, obelisks, and other pieces of stone, daily passing over them. Pliny relates that when M. Scaurus wished to transport 360 marble columns, each 38 feet long, from the place where they had been used, in his theatre, to the Palatine Mount, the inspectors of the sewers demanded some security to repair any damage which might occur. After Scaurus had completed his house, the sewers were examined, and found not to have sustained any injury; they formed a portion of the roads under

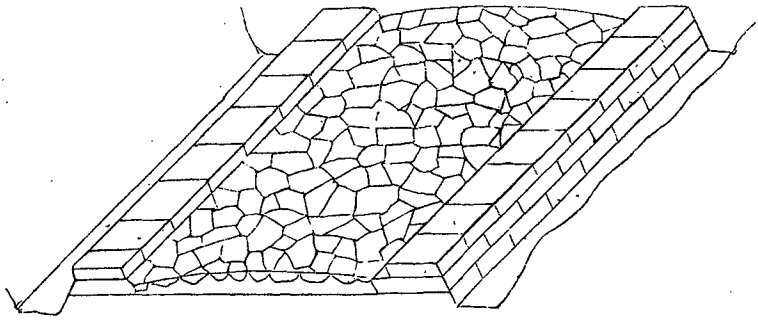


Fig. 162. CARRIAGE ROAD.

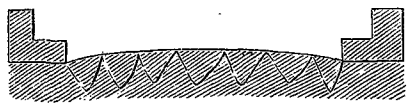
which they passed, and were intended not only to effectually drain all that might be injurious to health and cleanliness, but also to afford a better foundation.

Over these vaults was laid a bed, on which rested the materials forming the road, which was paved in the same manner as the bridges.

In Rome there were 31 principal streets, and about 422 lesser. According to Pancerolus, one is mentioned as made by Heliogabalus from his palace, called Plateas Antoninianas, which was paved with stone or marble from Lacedæmon, of a beautiful green colour, mixed with porphyry.

The Materials used by the Romans for road-making were of two kinds; the stones which formed the mass, and the cement which united them. According to Vitruvius, there were three sorts of stone quarried, of different degrees of hardness. The soft, when first taken from the quarry, was easily cut and rendered useful for building purposes, and when protected from the weather, and not in contact with the ground, had considerable durability.

That stone which sustained weight, and the action of frost, without splitting, was mostly used on the great roads, and was called Saxum or Silex.



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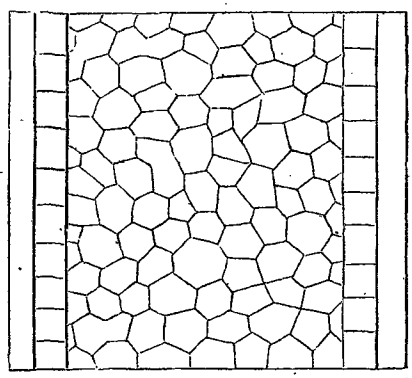


Fig. 163. PLAN.

In the formation of their roads, the Romans used every kind of stone that could conveniently be obtained; after the line was set out, excavations were made at the sides, from whence was extracted any material that was serviceable; and, establishing a solid and durable bed, by closing the ground with iron rammers made for the purpose, they spread the different strata which composed the area or mass of the road. These were called statumen, rudus, nucleus, and summa crusta, which together were in thickness about 3 feet.

In the great military roads, the statumen or lowest bed was formed of two courses of flat stones laid in mortar: over this was the rudus, or rubble, well beaten; then the third layer, called the nucleus, a sort of *beton*, was spread; this was formed of coarse gravel and lime, used hot; on this was bedded the summa crusta.

When the road was carried over marshy districts, a framework of carpentry was provided, called "contignata pavimenta," and the

frame itself contignationes. The joists or sleepers were termed coaxationes or cassationes, and were made of an oak called esculus, because it was not subject to warp or shrink. To protect this timber from the effect of the lime mixed with the other materials, they covered it with a bed of rushes or reeds, and sometimes straw. On this stratum of reeds or straw was laid the statumen or foundation.

The second bed was made of broken stones mixed with lime, which Isidore calls rudus. When this material was composed of stones freshly broken, it was called rudus novum; to three-fourths was added one-fourth of quick-lime. But when the material came from old buildings, it was called rudus redivivum, and then an additional portion of lime was used, two parts to five, and the work termed ruderationem; the rammer or beater was employed to strengthen, equalise, and smooth it. This composition, whether formed of gravel or debris, was 9 inches in thickness after it was thoroughly rammed. Over this tarras or ruderation, a cement was laid for the third bed, composed of brick, potsherds, broken tiles mixed with lime, using one of lime to three of brick. This was spread over the ruderation in a thin layer, to receive the fourth bed or paving, which served as a covering to the entire work, and was called in consequence summam crustam. The third bed or nucleus was the softest layer of the whole, interposed between what was harder. The stones and cement which formed the road were not less than 6 inches in thickness, and the entire mass laid upon the framework of carpentry was 15 inches.

The unpaved roads of the Romans were called by Ulpian vias terrenas, to distinguish them from those dressed with stone or gravel; and they were regulated by similar laws and ordinances as the others. The road from Spain into Italy, through Nismes, was of this kind, and only passable during the summer months. In the winter and spring, it was in a soft state, from the water which came down from the neighbouring mountains, though Strabo mentions several wooden and stone bridges and ferries.

These roads, so liable to be broken up by the torrents, were exposed to the action of the sun and wind, all shade being removed, that they might speedily dry.

Appian Way, or road to Capua, a distance of 120 miles, was paved with polygons of lava. In A.U.C. 451, the first mile, from the Porta Capena to the temple of Mars, was paved as a way for walking and riding on horseback (semita), with hewn stones (pepperino); and in A. U. C. 453, the whole road was paved with lava as far as Bovillæ. (Livy x. 23. 47.) *Semita*, signifies without any reference to width, a *cordonata*, or a road up-hill, made with sunken broad and low steps, where sumpter cattle walk safely and comfortably; carriages, if at all, can only come down: *clivus* is a carriage road. A well-known inscription tells us, that there

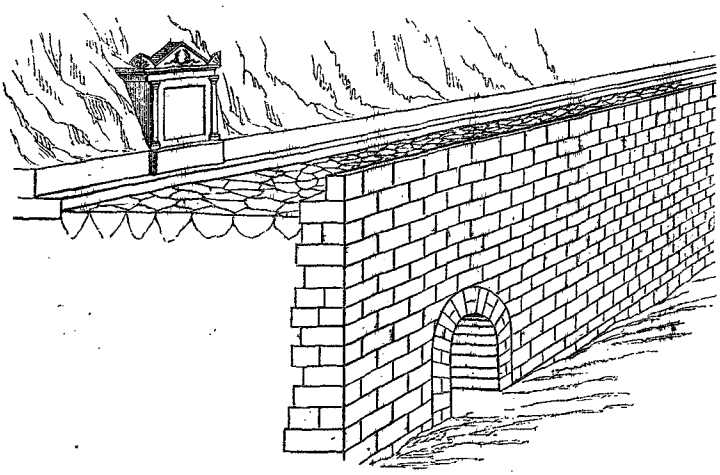


Fig. 164. APPIAN WAY.

was a clivus on the Appian road, near the temple of Mars, by the side of which the semita now necessarily assumed the form of a cordonata.

The Alta Semita, which led from the Subura along St. Agata to the Quirinal Hill, was such as the locality clearly shows. We find, in the gates of the so-called Cyclopean towns, Roman or Latin cordonatas, constructed entirely on the same plan as in the present day.

The Appian Way is remarkable for its foundations, its constructions over deep valleys

and hills, its bridges, and for the canal which accompanies it through the Pontine marshes, for the double object of draining the land and conveying the material of war from Latium to Terracina; this was important to a state not master of the sea.

The Setian was the military road to Campania from Velitræ to Terracina. To reach Terracina in one march from Cisterna would be impossible in summer; to encamp between the two places in the latter season and autumn would be fatal, in the rainy seasons equally impossible; in the hot months, one single night spent by an army in the neighbourhood of Cisterna would produce fever.

Forum Appii on the canal was also built by Appius Claudius.

The Pontine marshes were in all probability originally a bay behind the downs on the sea-coast; when this became filled with mud, by the river flowing into it, a marsh was slowly but gradually raised.

Prænestine Way. Where this magnificent road crosses the low marshy ground, constructions of the most solid kind were made, with arches turned in a symmetrical and perfect manner, rivalling the aqueducts for their beauty. The spandrills were filled in with rubble,

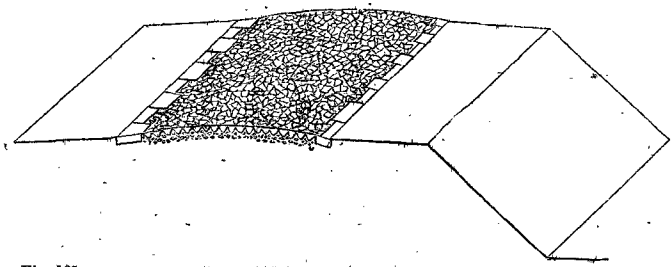


Fig. 165. VIAS TERRENAS ON THE PRÆNESTINE WAY.

and walls were carried on it, for the support of the level road above; the direction of this road is given in most of the Itineraries, and a description of the several statues which were situated upon it.

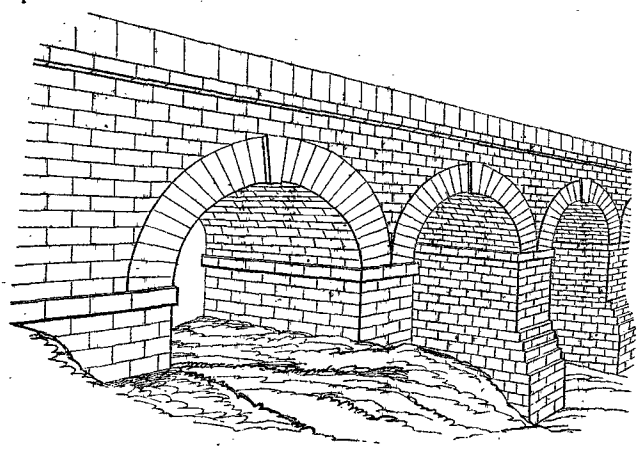


Fig. 166. PRÆNESTINE WAY.

The Bridges of the Romans are remarkable for their solidity, and for the almost universal adoption of the semicircular arch; the stone used in their construction is the hardest that the neighbourhood afforded; many have stood the force of violent torrents, and at the present day exhibit their original design, whilst others have undergone such changes, that their primitive features can scarcely be discerned.

One peculiar feature of Roman arches of great dimensions, and particularly of their bridges, is the leaving a projecting stone on each side, at about thirty degrees above the springing, upon which their centres were strutted, consisting of a longitudinal piece of timber, with inclined and perpendicular supports. Vitruvius, in lib. vi. cap. 11., observes that care

should be taken to discharge the weight of walls by arches consisting of wedges concentrically arranged; and further "that on buildings which are constructed on piers and arches, with wedges whose joints are concentric, the abutments should be wider than the piers, that they may have more power to resist the action of the wedges, which, when loaded, press towards the centre, and have a tendency to thrust them out." No particular rules are laid down for their proportion, which was probably left to the judgment and experience of the engineer. There is seldom much depth given to the voussoirs, which are of equal thickness throughout; and when the semicircle was complete, the spandrills were filled in with a concrete or rubble, which has hardened into a solid mass.

The Pons Milvius, or Emilius, two miles from Rome, on the Flaminian Way, consisting of four large arches and two smaller, has been altered at various times. The masonry

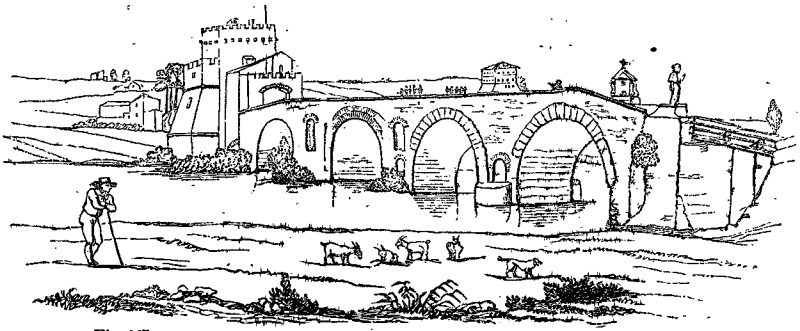


Fig. 167. PONS MILVIUS.

of the arches and tower at the extremity, as shown in the figure, with the openings in the piers, are said to remain as they were when Constantine pursued Maxentius, as he attempted to escape into the city, after his terrible defeat: being, however, pressed by the crowds who were flying to the narrow pass, he was forced into the water, and his body, weighed down by his massive armour, was afterwards found in the bed of the river. The arches vary in their opening from 51 to 79 feet 9 inches, but the whole of the water-way is in the clear 413 feet 3 inches; the breadth of the bridge is 28 feet 9 inches.

Pope Nicolas V. made some alterations in this bridge, and Piranesi, who has given an account of the change it then underwent, describes the two arches nearest the city as the most ancient: when the writer was at Rome, it was repaired under the direction of Valadier, who recased the ruined tower at the extremity, and gave it the character of a

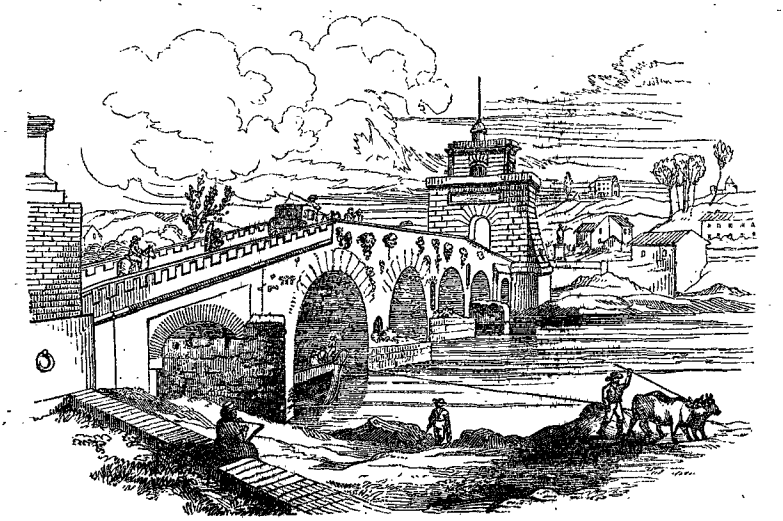


Fig. 168. PONS MILVIUS.

modern fortress. The views representing this bridge show the various alterations that have been made in it, and will enable the reader to form some idea of its construction.

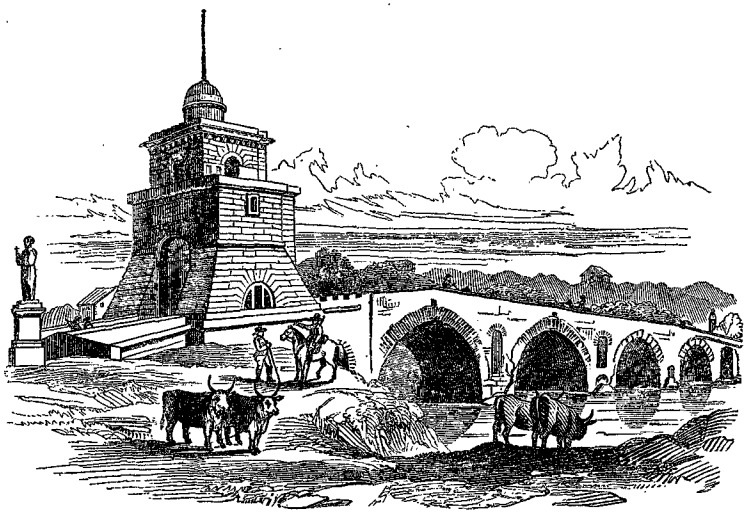


Fig. 169. PONS MILVIUS.

Pontus Salarius, *Ponte Salaro*, on the Teverone, is composed of three semicircular arches, 54 feet 6 inches to 69 feet span, and of two smaller arches, of 22 feet 4 inches span. It was built by Tarquinius Priscus 600 years, and restored by Justinian 570 years before Christ. The breadth is 29 feet; the stones which form the arches are large. It was near this bridge Manlius Torquatus took the collar of gold from the Gaul.

Ponte Rotto or Senatorius, on the Tiber, was the first stone bridge erected in the city; another was built on its site, at the time Fulvius was censor, which was completed by Scipio Africanus, and lasted till 1364. It was entirely rebuilt, in the year 1575, by Gregory XIII., and was nearly destroyed twenty-three years after by a flood; at present only one arch remains, to exhibit its former magnificence: the piers are ornamented with lions' heads holding a metal ring, and they have niches adorned by columns; the arch is composed of one row of voussoirs, of equal thickness, accompanied by an archivolt, the mouldings of which follow the curve: it is also decorated with the sculpture of two marine horses, admirably executed; the span of the arch is 80 feet, and the breadth 42 feet 8 inches.

Seven bridges formerly conducted over the Tiber to the Janiculum and Vatican Mount: these were, the *Pons Sublicius*, afterwards called Æmilius, built, as its name implies, of wood, and erected by Ancus Martius, according to Livy; this bridge stood between the Aventine and the Ripa Grande, where the foundation of one of its abutments remains. *Pons Palatinus*, or Senatorius, now Ponte Rotto; the *Pons Fabricius*, now Ponte de Quattro Capi, from a thermæ with four faces placed on it; *Pons Cestius*, now Ponte di San Bartolomeo; *Pons Janicularis*, of which there are no remains, though the Ponte Sisto occupies its site. *Pons Triumphalis*, opposite the hospital of Spirito Santo, has a vestige remaining, and here passed into the Campus Martius the victorious consuls to whom the senate decreed triumphal honours, followed by their soldiers, captives, and spoils: after entering the Porta Triumphalis, they passed the circus of Flora and Flaminius, the theatres of Pompey and Marcellus, the portico of Octavia, and the Circus Maximus, traversed the Via Triumphalis, entered the Via Sacra, passed between the Coliseum and temple of Venus and Rome, crossed the Roman Forum, and halted at the temple of Capitolinus.

The *Pons Ælius*, or Ponte San Angelo, the ancient piers of which remain, was the seventh bridge over the Tiber, which, a few miles above Rome to the sea, is in width about 300 feet on an average, therefore not difficult to span by a bridge. Its banks above and below the imperial city, once adorned by graves and gardens, in which were the villas of the wealthier Romans, as well as the villages and palaces on its meandering banks, are now only traceable in their ruins. "Deo gratissimus amnis," the distinguished Tiber, has been so woven into the recollections of the classic traveller, that it can never be forgotten.

Ponte Salara, on the Anio, consists of one large arch, nearly semicircular, 95 feet 9 inches span, and two lesser openings. The date of its construction is not ascertained.

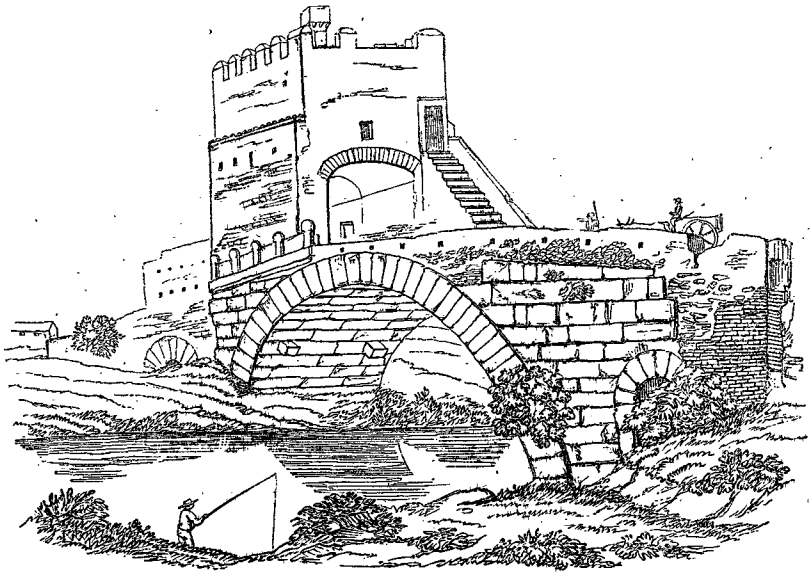


Fig. 170. PONTUS SALARA.

The Bridge Nomentano, over the Anio or Teverone, near Mons Sacer, so celebrated as the spot where Menenius Agrippa met the plebeians, and told them the story of the belly and members; the consequence of their disagreement he likened to the dissension of the

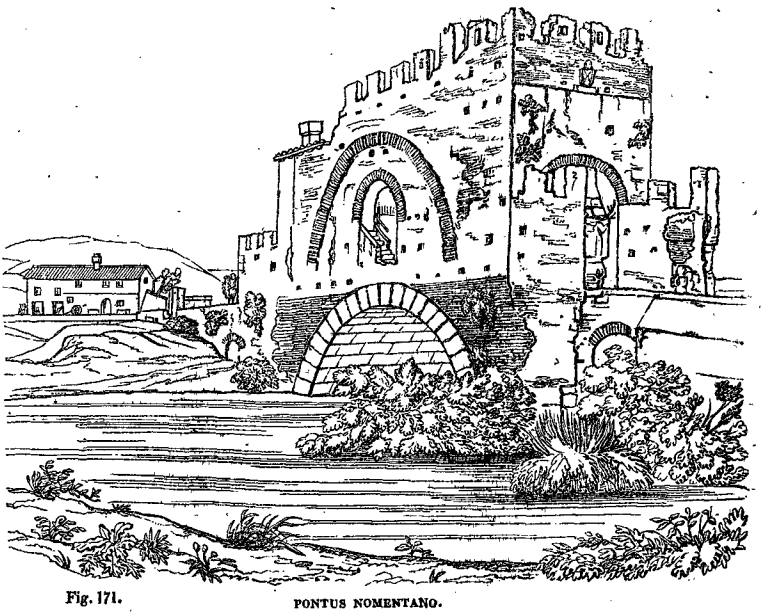


Fig. 171. PONTUS NOMENTANO.

commons and the patricians, and by this fable won over the people from their attempts to put the consuls to death. The stone arch, a part of the ancient bridge, now sustains a tower, constructed probably in the fifth or sixth century, which has undergone several changes during the middle ages, when it was used as a fortress: in its present state it is a very picturesque object. Many of the Roman bridges had towers either on them, or at their extremities, encircled with battlements, which served to defend the passage, as also to collect their dues.

It is to be regretted that Vitruvius has not left an account of the manner of building bridges in his time, or that he should not in the slightest degree have alluded to the subject: all that we know of them is by studying the numerous remains which span the rivers of Europe, where the great roads required them. The vaults are worked much in the same manner as those of the triumphal arches: large blocks were generally selected, and truly cut; one course of deep vousseirs supported a mass of rubble, on which the road-way was laid; precautions were also taken to defend the piers, and to carry off the water from the road, by means of pipes and drains. All the refinement adopted by modern constructors is traceable to the examples left us by the Romans, and we cannot too highly prize their design, and economical use of material: solid stone was employed where necessary, with a filling in of concrete equally durable, resisting in many instances all the efforts of time and weather.

Pons Janiculum or Ponte Sisto has been several times rebuilt; the present was executed in the time of Sixtus IV., in 1478. It is composed of four arches, from 53 feet to 70 feet span: in the distance is seen the Farnese palace.

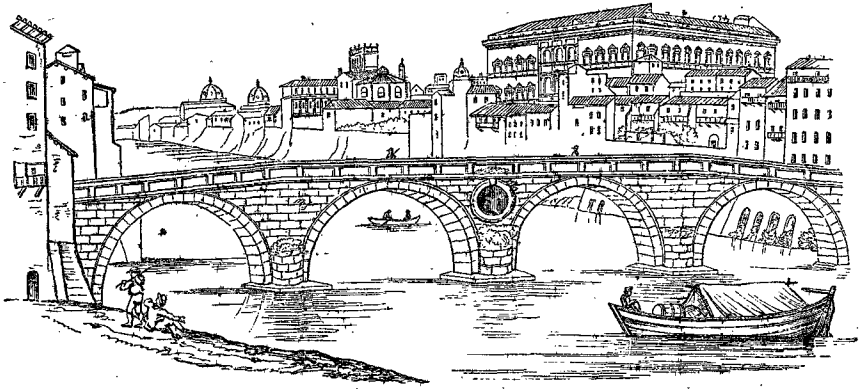


Fig. 172. PONTE SISTO.

Pons Fabricius, and Pons Cestius. — These bridges, now called Ponte Quatro Capi and Ponte Ferrato, are situate at Rome, on the two arms of the Tiber, which surround the

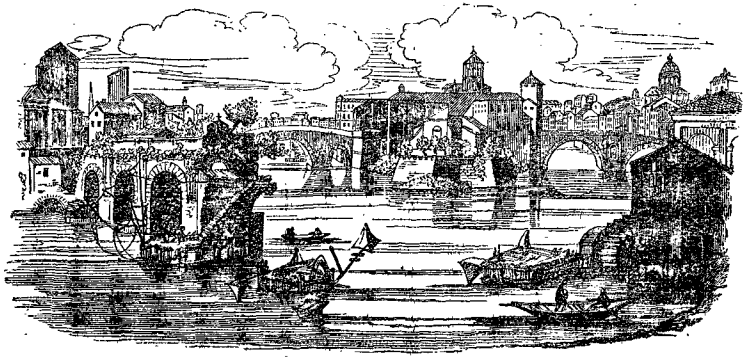


Fig. 173. PONS FABRICIUS AND CESTIUS.

island of St. Bartholomew. The first was repaired in 1680, by Pope Innocent XI.; the second, in 380, by the emperors Valens and Valentinian. The Pons Cestius consists of a single arch, 78 feet 9 inches span: the width is 49 feet 3 inches; the two arches of the Pons Fabricius are 82 feet span. In the pier which separates them is a passage accompanied with pilasters: the cornice which surmounts the bridge is ornamented with mutules; the breadth is 49 feet 3 inches. The Ponte Rotto, in its present state, occupies the left of the view.

These two bridges were founded, it is said, on a bad soil, by means of a mass of masonry, consisting of right and inverted arches, carefully cut in freestone. Piranesi gives the details of this remarkable construction, but does not pretend to guarantee its authenticity.

Bridge at Rimini, built by Augustus, was regarded by Palladio as the finest he had seen, and most of his designs are copies of it. It consists of five semicircular arches; the two outer are 23 feet 5 inches span, the three intermediate 28 feet 9 inches. The thickness of the piers is nearly equal to half the void of the arches; they are formed by a pedestal rising 13 feet 1 inch above the water; this is surmounted by niches, accompanied by columns which support an entablature; the cornice which crowns the bridge is sustained by modillions in very good taste.

Bridge of St. Angelo. — This splendid monument, which formerly bore the name of Pons Ælius, from the prænomen of Hadrian, was constructed by him in A. D. 138, opposite the tomb which he had erected. The piers were surmounted by eight colossal columns bearing bronze statues; these columns were destroyed during the troubles in Italy, when a great crowd occasioned by the procession of the jubilee thrust the parapets into the Tiber: Pope

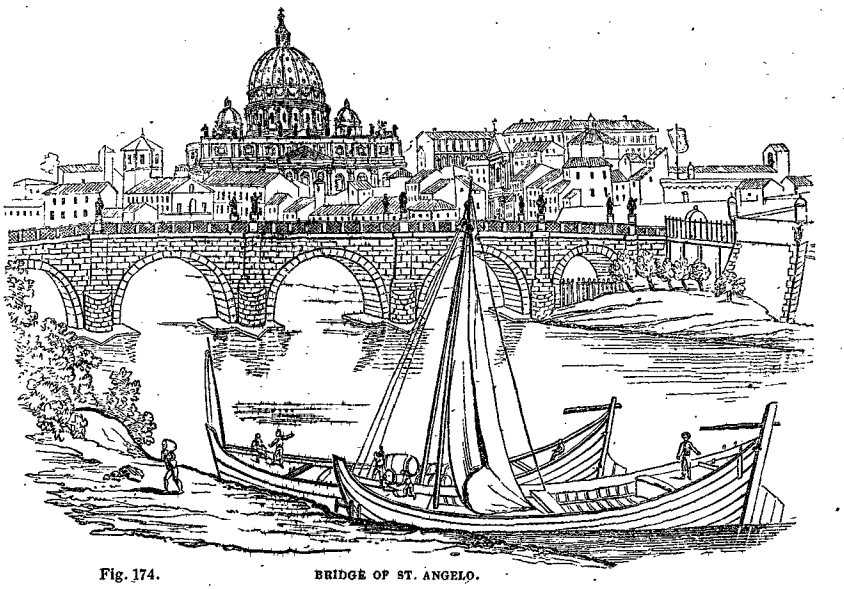


Fig. 174. BRIDGE OF ST. ANGELO.

Clement IX. restored them in 1668, according to Bernini's designs. It was then decorated with pedestals of white marble, bearing ten colossal statues of angels. The semicircular arches, from 26 feet 3 inches to 62 feet 4 inches span, have archivolts around them: they form a water-way of 370 feet 7 inches. The breadth of the bridge is 50 feet 9 inches.

Pons Mammea, on the Teverone, four miles from Rome, consists of three arches, 53 feet 2 inches and 64 feet span. It was erected by Antoninus Pius, about A. D. 147, and restored in 229 by Mammea, mother of Alexander Severus, whose name it bears. The centre arch is ornamented with a Roman eagle holding a thunderbolt in his claws, surrounded by a laurel crown. The cornice is sustained by large consoles; the breadth of the arch is 29 feet 3 inches.

The Berghette Bridge, on the Tiber, consists of three arches, 83 feet 4 inches span. The upper part of the piers is pierced, and presents semicircular arcades.

Bridge on the Bachiglione, near Vicenza, consists of three arches, one of which is 68 feet 11 inches, and the two others 55 feet 5 inches; it is one of the finest bridges in Italy. The piers are decorated with niches containing statues, and two composite columns, which

are surmounted by an entablature. The cornice, level over the centre arch, and inclined over the two others, is sustained by strong modillions. The breadth is 55 feet 9 inches.

Ancient bridge at Vicenza, has been described by Palladio: the centre arch, 34 feet 8 inches span, is very ancient; the two others are modern, their span is 25 feet 11 inches. The width of the piers is 5 feet 9 inches; that of the bridge, 27 feet 7 inches. The versed sine of the arcs of which the arches consist is two-thirds of their diameter. They are adorned with archivolts: the cornice is sustained by modillions.

Pilantio Bridge, over the Teverone, near Rome, on the road to Tivoli, is composed of three arches, arcs of circles. The thickness of the piers is one-fourth the span of the arches, they have no starlings. It is constructed with very large stones; the total length is 170 feet 8 inches.

Bridge and Aqueduct of Spoleto, was built near the town which bears that name, in A. D. 741, by Theodoric king of the Goths. It consists of ten large Gothic arches, each 70 feet 3 inches in span, and sustained by piers 11 feet 10 inches thick. The centre arches over the river Moragia are above 328 feet in height. The others are much lower, the two slopes on which they are built being very steep. At the upper side of the bridge, thirty small Gothic arcades sustain an aqueduct, serving to convey water into the town. This monument, of a very bold execution, and built of small hard stones, remains entire, and still conveys water to Spoleto. The total length is 810 feet 5 inches, the breadth 42 feet 8 inches.

Bridge and Aqueduct of Civita Castellana. — This work is part of a causeway, constructed about 400 years B. C., to approach Castellana, 820 feet long, 33 feet wide, and 128 feet high, pierced in the centre by nine great arches loaded with about 13 feet of earth. The three centre arches are 87 feet 3 inches in span, the others 63 feet 11 inches. Some of the piers are strengthened by counterforts, and others by flying buttresses with a detached base.

Bridge on the Cremera, at Civita Castellana. This bridge, celebrated as the place where the Veii gained an advantage over the Fabii, B. C. 447, is constructed of brick, stone, and marble. It consists of three arches, the centre is 74 feet 5 inches span, and the two others 50 feet 2 inches; the breadth is 34 feet 2 inches. The foundation is established on a radier or timber platform, on account of the instability of the soil, on which are inverted arches of the same span as those of the bridge.

Trajan's Bridge over the Danube. This colossal work, the most magnificent in Europe, was built under Trajan by Apollodorus, his architect, about A. D. 120. The rapidity and depth of the current in the place where it is situated added to the difficulties of the work: a general foundation was constructed by means of large barges filled with stones, lime, and sand, sunk at the bottom of the river; sacks of different sizes were thrown into the interstices, filled with the same materials. On this base the piers were established. The bridge consisted of twenty semicircular arches, 180 feet 5 inches span. Their springings were raised 46 feet above the general level of the river; the thickness of the piers was 64 feet, they were 85 feet 3 inches wide; the stones used were enormous, but it was destroyed a short time after its construction. Some of the piers are still to be seen with the springings of the arches which they supported.

M. de Marsigli, in his work on the Danube, charges Dion Cassius with having asserted that the arches of Trajan's bridge were of stone, and says that they are represented as wood on the bas-reliefs of Trajan's Column.

Bridge near Terni, on the Nera, whose ruins still exist, consisted of seventeen arches, 131 feet 3 inches span; its piers were 27 feet 6 inches thick, and 111 feet 6 inches to the springing: its total length was 2592 feet, and its width 32 feet. It was constructed of large blocks of stone, and the piers had no starlings; the foundation of intermediate piers may be seen, which divided the opening of each arch into three parts, intended probably to support the centres during the construction of the vault, and afterwards demolished. The bridge has no parapets, and in their place are white marble blocks, between which chains are suspended as guards.

Bridge of Capo Dorso, believed to have been built in Sicily by the Romans, consists of one semicircular arch 96 feet span. Its small width may cause us to doubt its Roman construction, being only 17 feet.

The Bridge de Boisseron, upon the Domitian Way, near Nismes, said to have been constructed by C. Domitius Ænobarbus, has five semicircular arches; the centre spans 30 feet 9 inches, the two contiguous 28 feet 9 inches, and the others at the extremities 19 feet 6 inches; the piers are 9 feet 4 inches; the entire width of the bridge, 11 feet 6 inches.

All the arches spring from the same level, consequently the roadway and parapets incline from the centre. The piers between the springing of the arches are perforated, to afford more water-way, and to prevent too great a pressure at the time of floods.

In this bridge the projecting voussoirs, on which the timbers, struts, or centres, were supported at the time of its construction still remain; in almost all the examples where hard stone was used for the turning an arch, these projecting blocks are to be seen, as in the

Pont du Gard. Few works have undergone less change than the Bridge of Boisseron, or retains more of the primitive character.

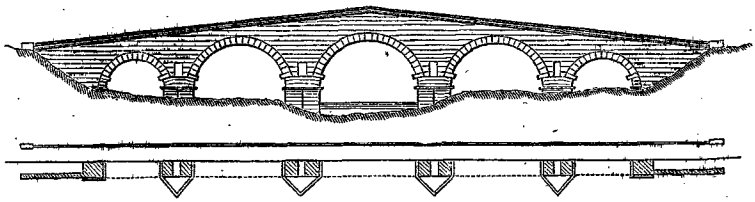


Fig. 175. BOISSERON.

The Bridge of Sommieres, over the Vidourle, a short distance from Nismes, consists of seventeen arches, all semicircular, built with a durable stone from the quarries of Pondres, situated near the city. All the stones which form the level courses are dressed with great care, and their horizontal and vertical joints worked with precision, little mortar being used; they appear to have been first bedded, then run with a fine cement or liquid mortar.

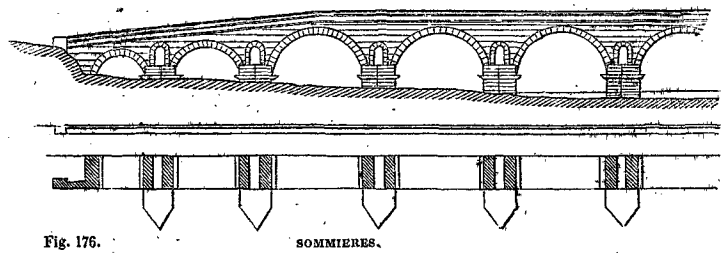


Fig. 176. SOMMIERES.

The middle arch spans 32 feet, the others 30 feet, and the piers are 10 feet; the whole length of this fine remain is 620 feet, and the entire width from face to face 22 feet 2 inches.

The Bridge of Ambrussum, upon the Domitian Way, over the Vidourle near Nismes, was constructed by Augustus about four years before the commencement of the christian era.

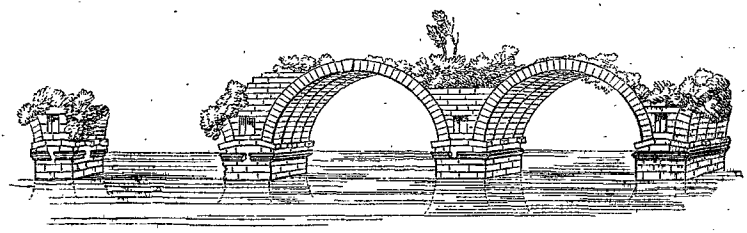


Fig. 177. AMBRUSSUM.

It seems to have resembled in workmanship that at Boisseron. The arches, formed of four circles of voussoirs, are all destroyed excepting two, which remain in the middle of the stream.

The Triumphal Bridge of St. Chamas, over the small rivers called Tolubre, has an arch at each extremity, a perfect and unique example of this kind of bridge. It was built by Augustus, or in his time, as an inscription on the frieze indicates.

L. DONNIUS. C. FLAVOS. FLAMEN. ROMÆ. ET.
AUGUSTI. TESTAMENTO. FIEREI. JUSSIT. ARBITRATU.
C. DONNEI. VÆNÆ. ET. CATTEI. RUFFI.

By this inscription we learn that it was erected according to the will of Donneius Flavos, priest of Rome, and Augustus, under the direction of Donneius Væneus and Caffeus Ruffus. But it does not assert that Donneius Flavos was cotemporary with Augustus, or which of the emperors of that name is referred to.

The character of the architecture is the best met with in Gaul; the stone was brought from the neighbouring quarries of Hassissane, and the courses are regularly laid and jointed.

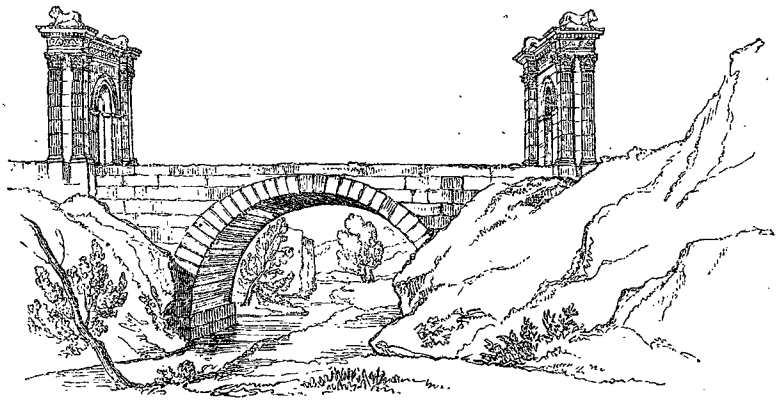


Fig. 178. BRIDGE AT ST. CHAMAS.

The span of the arch is 42 feet, and measured on the soffite its breadth is 19 feet 9 inches; there are 39 voussoirs, 3 feet 5 inches in depth; on each side one projects 13 inches, to support the centre.

The clear width of the roadway between the parapets is 15 feet 6 inches, and the length between the triumphal arches at each extremity 74 feet 9 inches.

The opening of each of the triumphal arches is 11 feet 8 inches, and the height to the springing 9 feet 4 inches; the total height to the top of the cornice 23 feet, and the entire width, as measured along the frieze, 24 feet, forming nearly a square.

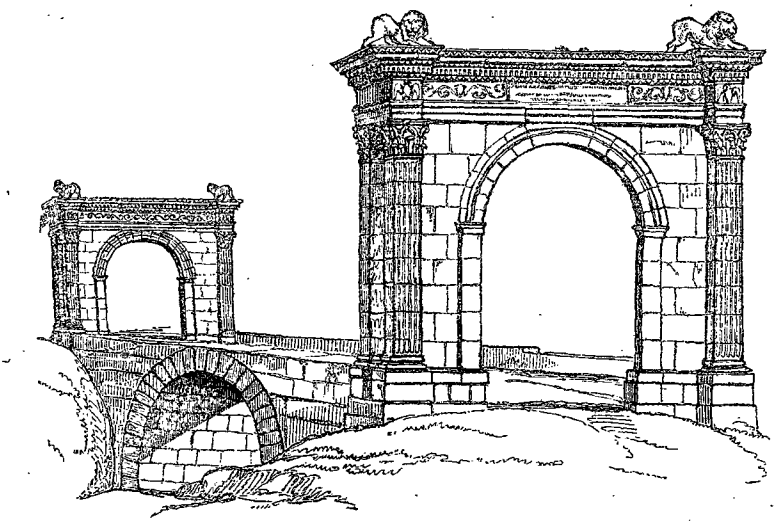


Fig. 179. BRIDGE AT ST. CHAMAS.

The writer in 1817 found this beautiful bridge as perfect as here represented. Some of the stones had been repaired, and a few of the upper courses had smaller introduced; based upon a rock, and constructed with the greatest care, it promises to remain as many centuries as it has already done, a monument of the taste and skill of Roman engineers. Palladio and other architects have designed bridges with triumphal arches and covered ways, in

imitation, and none have surpassed in merit this simple and unique example, which deserves much to be studied.

At Vaison are the remains of a bridge of one arch, which, when in a complete state, must have somewhat resembled the preceding; the voussoirs are admirably worked, having

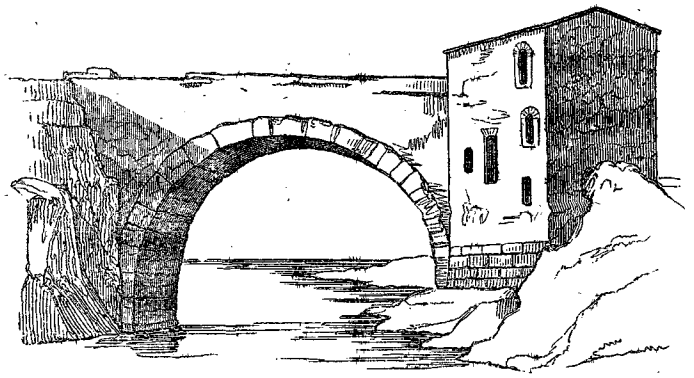


Fig. 180. VAISON.

retained their original position; the curvature of the arch has not undergone any change, and the whole is as solid as when first constructed.

The Bridge over the Allier, at Brioude, is also Roman, consisting of one arch; in the southern part of France are many such remains, particularly on the ancient routes; through

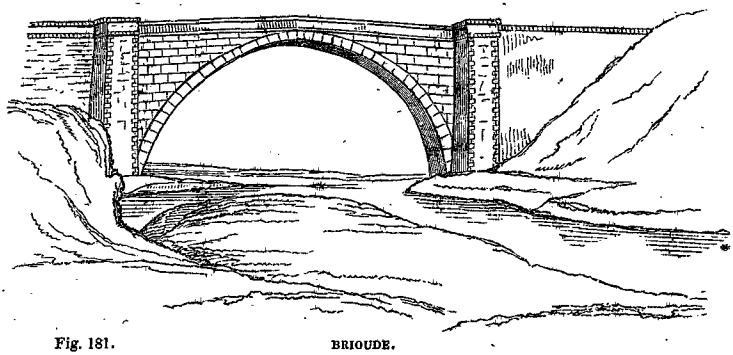


Fig. 181. BRIOUDE.

Provence, the stones are laid in regular courses, and but little mortar used, the voussoirs cut very true, and bedded with care.

Bridge at Saintes over the Charente is an ancient structure: above the centre pier, in 1812 was erected a triumphal arch brought from Mediolanum, or Civitas Santonium,

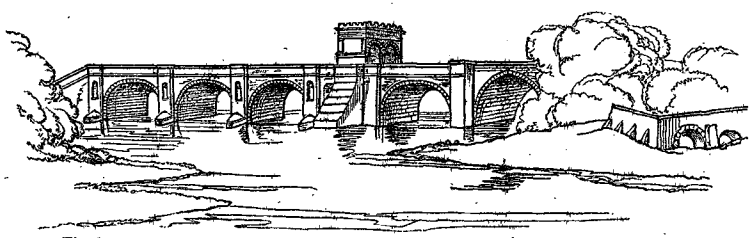


Fig. 182. SAINTES.

which once formed the termination of a bridge, as at St. Chamas. The proportions given to the architecture are not elegant, and on inspecting it, we are induced to believe, that

originally its height equalled its entire width: it has been said by some writers, that the two arches were not so coupled in the situation from whence they were brought, but that a

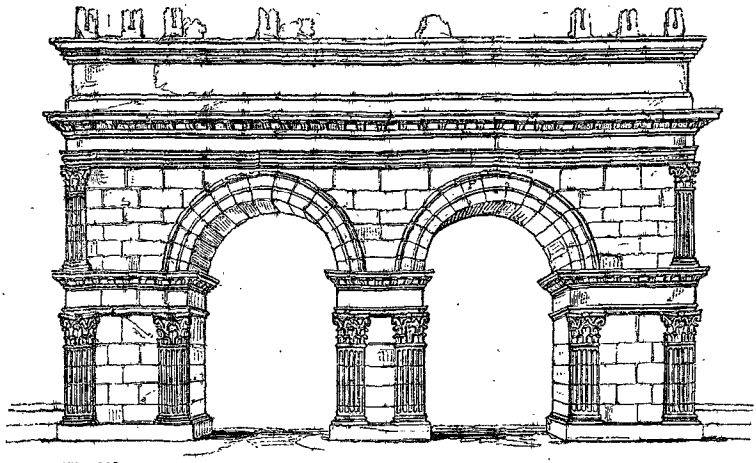


Fig. 183. MEDIOLANUM.

single opening terminated each end of the original bridge, as was the practice of the Roman engineers. In Italy we often have the foundations of piers of triumphal arches, and pedestals for statues on the abutments of bridges; these not only added weight, where it could give additional strength, but contributed much to the beauty of the structure; masses of stone built over the springing of an arch assisted in preventing any spreading or slipping upon the haunches; a triumphal arch placed at each extremity would have the same use, and contribute much to the effect. A vast catalogue of Roman bridges might be made, and it is somewhat remarkable that a selection has not been measured by the modern engineers, and classed according to the span of their arches and boldness of construction. The great rivers of Italy, France, Germany, Spain, and Portugal, all afford examples, some erected where the water is broad, rapid, or deep, or on foundations which presented considerable difficulties. Timber platforms on piles were universally adopted on soft ground, and a concrete, formed of hydraulic mortar, is found to have been made use of very generally throughout Italy, wherever it could be applied.

In Italy, the Roman bridges have generally served for foundations for the modern; many have had their semicircular arches altered during the middle ages, and in some instances, timber constructions are formed upon the massive piers, which time and the floods have spared. One great cause of their destruction was the elevation of the beds of the rivers, in some instances so great, that the openings have entirely silted up, and been closed by the deposit; in consequence the structure, not affording sufficient water-way, has been carried away by the flood.

Pavia over the Tessin.—A covered bridge, of Gothic construction, built of brick, consists of seven arches, each 70 feet span, and 64 feet in height. The piers, whose breadth is 16 feet, have a rounded form, but longer in the direction of the stream than across it. The tympanums of the arches are pierced, resembling a curvilinear triangle two sides of which are parallel to the entrados of the vaults; thus the weight in a great measure rests against the keystones, the thickness of which is 5 feet 6 inches. The bricks with which these vaults are constructed have the form given to them suited to their position as voussoirs, and are pierced in the middle to diminish the weight. The piers are covered with white marble, the arches have an archivolt, and the whole is crowned with a Gothic parapet of the same material, worked out to give it the greatest possible lightness; each footway has a covering supported by two rows of small coloured marble columns, 9 inches in diameter, 14 feet 4 inches apart, whose bases and capitals are of white marble. The vaulted coverings are ornamented with gilt arabesques, on an azure ground, and sustain two terraces, which are ascended by steps, placed at the extremity of the bridge. The thrust of the vaults is opposed, as in many other Italian buildings, by iron rods placed on a level with the springing. This beautiful work was executed by Galeazzo Visconti, Duke of Milan, to which prince the city owes the Charter House, Hospital, and Lazaretto.

Bridge of the Goldsmiths, at Florence, over the Arno, called *Ponte Vecchio*, was rebuilt in

1345, after the designs of Taddeo Gaddi; it has three arches, the segments of circles, from 94 feet 6 inches to 85 feet span; and from 15 feet to 12 feet 10 inches rise. The thickness of the key-stone is 3 feet 3 inches, the springing line of the arches is 11 feet 5 inches above the level of low water. The thickness of the piers is 20 feet 4 inches, and the breadth of the bridge 105 feet. It is built on piles, and a general framework; on the upper side of the bridge is a covered gallery constructed by the Medici, and forming the continuation of a passage from the Pitti palace to that of the old Ducal. Under this gallery, on the middle of the bridge, are left open three arcades; the goldsmiths' shops occupy the sides. The bridge of the Goldsmiths is one of the first modern bridges where a segment was employed; its springing is near the level of high water.

Bridge of the Carraja at Florence, rebuilt by Taddeo Gaddi, consists of five arches, which are segments, 57 feet 5 inches to 88 feet span; the versed sines are 12 feet 5 inches and 26 feet 10 inches; it is built on piles. The facing walls are of squared stone, the rest, as well as the arches, are in moellon.

Bridge of Alexandrie on the Tenaro, was built anterior to the year 1487, when four of its arches were taken out, and reconstructed. It has ten arches, segments of circles, from 52 feet 5 inches to 95 feet 2 inches span. The upper part forms a covered gallery, 24 feet wide, the roof of which is supported by small arches, 7 feet 8 inches span; during the time Piedmont was occupied by the French, they constructed a general platform underneath this bridge, to form a movable sluice, by which they could fill the ditches of the citadel in case of siege.

Ponte Felice, over the Tiber at Rome, was built in 1587, under Sixtus V., by Dominica Fontana; it is composed of four arches; the two outer are 38 feet 9 inches, and the two middle 51 feet 2 inches span, nearly semicircular, and supported by piers 24 feet 7 inches thick. Over the arches are sculptured bas-reliefs.

Bridge over the Arno at Pisa, called the middle, was constructed after those at Florence, in 1660, by François Nave. It is composed of three segmental arches, from 68 feet to 73 feet 7 inches span, and from 12 feet 2 inches to 14 feet 2 inches in height. The piers are 19 feet 3 inches in thickness; the outer work is marble, and the rest brick; the left pier is surrounded by a starling, which serves to strengthen the foundations.

Bridge on the Rialto at Venice was built in 1578 by Michael Angelo, and has a single arch 96 feet 10 inches span, and 20 feet 7 inches high. The footways are supported by corbels provided with ballusters; on the two sides are rows of shops, formed by marble arcades; the interval which separates them constitutes three passages, the middle being the largest; this bridge is not intended for carriages. The approaches are steep, aided by marble steps.

Bridge at Vicenza resembles the Rialto; the slope is still more steep, and is only used by foot passengers; it has a single arch 101 feet 4 inches span, and 30 feet high.

Ponte Corvo near Aquino, over the Melza; in the fourteenth century, it was in vain attempted to construct a bridge in this situation; the bad quality of the foundation and the rapidity of the torrent rendered all the efforts of the kings of Naples useless. Stephano del Piombino at last proposed to construct one on a circular plan, whose convexity should be opposed to the action of the current, and this idea was adopted, it being considered that such a form would ensure solidity. This bridge was raised on a timber framework, whose surface lay 6 feet 6 inches below the mean level of the water. The piers are formed of large blocks of stone, securely cramped, and defended by several rows of piles, their base has four courses of stone, from 13 feet to 16 feet 5 inches long, also cramped, and presenting large sets-off; as has been observed, the foundations have a circular plan, whose radius is 577 feet 6 inches. The arches are seven in number; they are from 74 feet 5 inches to 93 feet 10 inches span; the thickness of the piers varies from 10 feet 8 inches to 12 feet 9 inches; the breadth of the bridge is 42 feet 7 inches. The torrent being dry for a considerable part of the year, the foundations were laid in one campaign; a great number of workmen as well as soldiers were employed; the following year they raised the piers above the mean level; Stephano died before the completion, and was succeeded by his son, Augustino, aided by Joconde of Verona, who was afterwards called to Paris to construct the bridge of Notre Dame; it was finished in 1505. Its solidity is not increased by the circular form given to its plan, but by the construction of the frame-work, which would equally have resisted the action of the current had it been in a right line; if some wearing away had occurred, it would only have been partial, and it is impossible that the bridge could have been carried away in one piece, which might happen to a dam 30 or 40 feet long: the disposition adopted has the inconvenience of obliging the piers to be inclined towards the current, which presents more resistance to the stream, and consequently injures the solidity of the bridge.

Bridge of the Trinity at Florence was constructed in 1750 by Ammanati, a celebrated architect. This bold work consists of three arches, nearly elliptical, the curve being portions of two parabolic arches, whose angle at the top is masked by an escutcheon. The span of the arches is from 87 feet 7 inches to 95 feet 10 inches; the springings are 7 feet

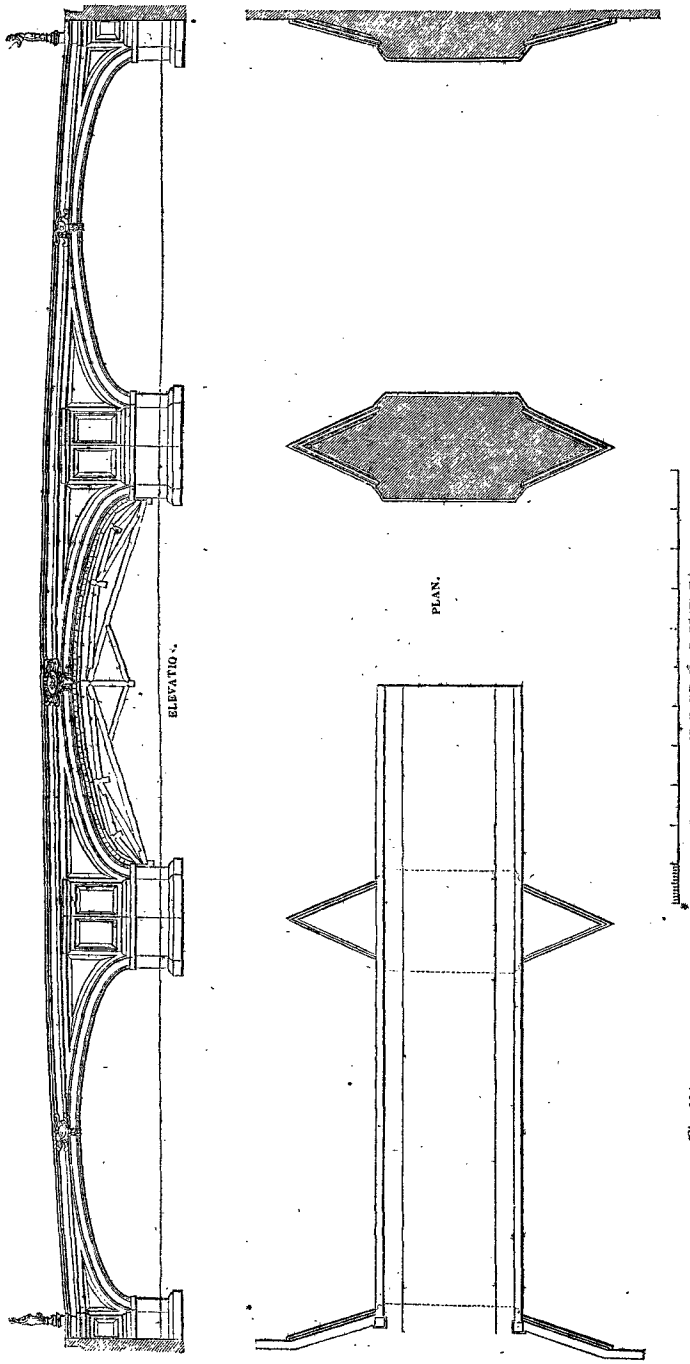


Fig. 184.

10 inches above low water, and the rise is one-sixth of the span; the arches are 3 feet 2 inches thick. The breadth of the piers is 26 feet 3 inches, and that of the bridge, 33 feet 9 inches. The facings of the piers are worked stone, with well executed mouldings. The other parts of the structure are of rubble; the foundations rest on a general framework, surrounded and crossed by several rows of piles. A defect which occurred under one of the piers of the bridge was repaired in 1811 by the elder Goury.

Bridge of Verona over the Adige consists of three arches, 36, 50, and 160 feet span; the latter is the largest arch found in Italy.

Bridge on the Marachia, near Rimini, has five arches, from 23 feet 3 inches to 28 feet 9 inches span. The upper part of the piers has niches and columns, supporting entablatures.

Water. — The Romans bestowed unwearied pains to obtain pure and wholesome water; their military and civil engineers were always on the alert to ascertain its nature and properties throughout the countries where they were employed. Vitruvius observes that when C. Julius, the son of Masinissa, lodged with him, they frequently conversed on subjects of natural history, and that he had read most of the Greek authors, as Theophrastus, Herodotus, &c., with the greatest care and attention, for the purpose of ascertaining the qualities of the different streams and rivers. The vast sums of money expended to provide abundance of pure water for the inhabitants of the imperial city and the other towns of that vast empire, gave employment to many engineers; it is curious to examine the opinions of Greek and Roman philosophers upon the nature and properties of this element. Thales, the Milesian, taught that all things originated from, and the priests of Egypt believed that all things were composed of, water; that it was essentially necessary for the purposes of life, for pleasure, and for daily use, was universally felt and admitted.

When the Roman engineer wished to discover the source of a stream, he was instructed to lie down on the ground a little time before sunrise, and to notice where the vapours rose into the air; he was then to dig at that spot and commence his search. In clay it was supposed the supply was small, and not of the best quality; but in veins of gravel that it was well flavoured; when the bulrush, the wild willow, the alder, reeds, ivy, and similar plants abounded, abundance was always relied on. In situations where these indications were not met with, they adopted the following plan: a hole three feet square was dug, at least five feet deep, and in it, about sunset, a brass or leaden vessel was placed, rubbed inside with oil. Thus prepared it was inserted, and the upper part of the excavation covered with reeds or leaves, over which the earth was thrown. If on the following day, on opening the hole, the inside of the vessel exhibited any drops of water, it was expected that a quantity might be obtained. When the vessel placed in the pit was made of unburnt clay, it was often found destroyed by the moisture, which was considered a sure indication of the presence of water. A fleece of wool was often placed in a similar pit, and when water on the following day could be pressed out of it, an abundant supply was inferred. Lamps full of oil were placed in the pit and covered over, and when examined, if not exhausted, but still retaining some of the wick and oil, and presenting a humid appearance, it was shown that water might be found, as it was supposed that heat invariably drew moisture towards it. Such were the rude trials recommended previous to the sinking of a well, which were continued until the head of the spring was found; other wells were then dug around it, and by means of tunnelling connected with it.

Rain water was considered by Celsus the physician the most pure, and formed of the lightest vapours. Aristotle supposed that these vapours rose from the earth, into a cold region of the air, were then compressed into clouds, and afterwards condensed into rain; that such water collected into showers was cleansed by its passage through the air. And Vitruvius tells us further, that showers do not so frequently fall upon plains as upon high ground, because the vapours are driven to the mountains. The winds convey the water, when heated by the sun, from the low grounds to the higher, and thus keep up a constant circulation; and he further illustrates this by his observation of the drops of water which collect on the ceiling of a hot bath; hot vapours ascend at first from their lightness, and do not fall down, but when condensed, they drop on the heads of the bathers; so it is with air warmed by the sun, it raises moisture from all places, and gathers it into clouds, whilst the winds which blow from cold quarters bring dry air and not vapours.

Some hot springs produced excellent flavoured water, and many cold ones had both bad taste and smell; the Romans arranged these, made them serviceable to a variety of purposes, and had baths supplied with water adapted, as they supposed, to every species of malady. Some springs, where the water was acid, as those found at Lyncestis in Italy, the Velinus, and in the Campana near Theanum, had the property of dissolving the stone which forms in the bladder; eggs placed in such water had their shells softened and dissolved; lead became white by the application of an acid, and brass verdigris. Pearls and flint stones, upon which fire would have no effect, were speedily dissolved in the same way by the application of acids. Such were the qualities and properties they found in some of the waters, and the Romans seem on all occasions to have exercised their knowledge,

when they selected a spring, on which they considered the health of mankind so much depended. Before an open or running stream was laid on to a town, they examined the inhabitants of the neighbourhood; if strongly formed, fresh coloured, sound legs, and without blear eyes, they considered the water good. By throwing a drop of water into a clean brass vessel, if it left no stain, it was thought pure. And after boiling, if no sediment was deposited, it was equally so. If in the spring it appeared limpid and transparent, and no moss or reeds generated near it, the water was considered light and wholesome.

Instruments used by the Romans for Levelling. The libra aquaria and the dioptera were not for this purpose considered so correct as an instrument called the chorabates, which was a rod or plank, about 20 feet in length, mounted on a leg at each of its extremities, both of equal length. The rod and the legs were fastened or secured by diagonal cross pieces or braces, on which were marked correctly vertical lines. A plumb line attached at each extremity and acting over these diagonal braces indicated whether the instrument was level. When the wind prevented the plumb bobs from remaining stationary, a channel cut in the upper edge of the horizontal rod was filled with water, and if the water touched equally both extremities, the level was supposed to be correct, and then the observation of the descent or elevation of the ground was made with accuracy. Vitruvius observes that although Archimedes asserts that water is not level, but takes the form of a spheroid whose centre is that of the earth, yet the two ends of the channel on the rod will nevertheless sustain an equal height of water. If it be inclined towards one side, that end which is highest will not suffer the water to reach to the edge of the channel on the rod. So that though water poured in may have a swelling and curve in the middle, yet at its extremities it will be level. When this instrument was used, if the ground was very unequal, the feet were propped up, and supported till they were brought level. The other two instruments, as the water-level and the dioptera, are not very accurately described.

Conducting of Water. This was effected in various ways by the Romans, either in channels built to convey it, or in earthen or in leaden pipes. When channels or aqueducts were adopted, they were solidly and substantially executed, with a fall of not less than six inches in a hundred feet, and arched over at top, to prevent the sun from affecting the water. When the water arrived at the walls of the city, a reservoir or castellum was built, which contained three cisterns to receive it. In the reservoir were three pipes of equal diameter, so connected, that when the water overflowed at the extremities, it was discharged into the middle one, which supplied the pipes for the fountains; a second pipe supplied the baths, and a third the private houses. The water for public use was never deficient, nor could it be diverted if the mains or pipes were properly constructed. The private houses had a tax levied upon them, which was expended in keeping the aqueduct in repair.

When hills intervened between the spring head and the city, tunnels were driven under ground, with a fall of one in two hundred; when the material cut through was stone, a channel was formed in it; when of earth or gravel, side walls were built, and an arch turned over, through which the water was conducted. Wherever these tunnels were formed, perpendicular shafts were sunk every 120 feet distance. When the water was brought in leaden pipes, a reservoir was made near the spring, and other pipes of sufficient diameter conducted it to the city reservoir; these were made in lengths of not less than ten feet, out of sheet lead of different widths and weights; hence a sheet of 100 inches wide would make a pipe weighing 1200 pounds; 80 inches wide, 960 pounds; 50 inches wide, 600 pounds; 40 inches, 480 pounds; 30 inches, 360 pounds; 20 inches, 240 pounds; 15 inches, 180 pounds; 10 inches, 120 pounds; 8 inches, 96 pounds; and 5 inches 60 pounds.

When pipes of this kind were used, the lead varied in weight, though it was generally at the rate of fifteen pounds per superficial foot; if there was a uniform and proper fall, any little impediment was made up by means of substructions, or by taking a circuitous course, provided it was not too far about; the pipes were all laid with a regular and proper current. If the valleys were long, they took the slope of the hill, and when the water arrived at the bottom, it was carried across the valley by a low substruction at as great a distance as possible; a venter here prevented the water on its arriving on the opposite side or acclivity from bursting or destroying the joints of the pipes. Over the venter were placed lofty upright pipes, by which the violence of the air escaped. Thus when water was conducted through leaden pipes, due attention was paid to the fall of its descent, its circuit, its vent, and the compression of the air. It was, however, always found expedient, after the fall from the spring was obtained, to build reservoirs, at distances of 20,000 feet, to allow of repairs. These reservoirs were not made on any descent, nor on the venter, nor on a rise, nor in valleys, but only on plains.

When economy was considered, earthen tubes were substituted, not less than two inches in thickness, so made, that one end fitted into the other. The joints were then coated with a mixture of quick-lime and oil, and on the elbows made by the level part of the venter, instead of the pipe, was placed a block of red stone, so perforated, that the last length of inclined pipe, and the first length of the level part, were received into it. On the opposite sides, where the acclivity commenced, a block of red stone received the last length of the

venters, and the first length of the rising pipe. By this attention the tubes in their ascent and descent were never put out of order. In aqueducts there is generated a great rush of air, says Vitruvius, of force sufficient to break stones, unless the water is softly and sparingly let down from the head, and unless in elbows and bending joints it be restrained by means of ligatures or a weight of ballast.

When the water was first let down from the head, ashes were put in, which closed the joints where they were not sufficiently coated; earthen pipes were considered in some instances preferable, as when damaged, almost any one could repair them, and the water conducted by them was of greater purity. The Romans preferred earthen vessels to silver at their daily meals, the water preserving its flavour better in them.

When wells were dug, they were steined or walled round, to exclude filtration, and tanks and cisterns were frequently used to collect the rain, which were carefully built with the purest and roughest sand and broken flint, among which no single piece weighed more than a pound; very strong lime and sand, mixed in the proportions of five of sand and two of lime, formed the mortar. The flints combined with the mortar lined the sides and bottom of the excavation. Several divisions were made in these cisterns coated with cement, and the waters passing from one to the other, depositing its impurities, was rendered wholesome and fit for use.

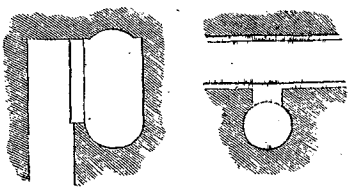


Fig. 185. PLAN OF WELL.

Pliny, lib. xxxi. cap. 31., informs us, that when water is to rise, the pipes must be made of lead, and that water will always ascend by itself to the height in the castellum from which it is delivered, or, in other words, find its own level; but that wherever there is a bend in the pipe, the lead must be increased in thickness at that place.

Fire Engines.—There can be no doubt but that the Romans had contrivances by which they could extinguish fires, for we learn by one of Pliny's letters to the Emperor Trajan, that when the town of Nicomedia, in Bithynia, was almost destroyed by fire, its ravages were increased by the laziness of the inhabitants, and the want of a proper machine—*sipho*—for extinguishing the flames. When Strabo, lib. v., alludes to the subterranean conduits at Rome, he mentions, that all the houses had *siphones* or water-pipes, and which probably could be applied to put out any accidental fire. Apollodorus, the architect, in his description of warlike machines, mentions the sipho for extinguishing fire, and observes, that if it is not at hand, leathern bags filled with water may be fastened to hollow canes, in such a manner as by pressing the bags the water may be forced over the flames. Such a *sipho* might throw water to a great height, and in the fourth century they were made use of. The Romans had many ordinances for the extinguishing of fires, and Ulpian, *Digest*, xxxiii. 7. 18., when mentioning those things which ought to belong to a house when sold, names the *siphones*, which have been supposed to be fire-engines. Seneca observes that the height of the houses at Rome rendered it impossible to extinguish fire, in consequence of the narrowness of the streets.

Form of the Pipes. These were not truly cylindrical, as has been commonly supposed, but their section that of a pear; the upper part being gathered in formed an edge where it was soldered. On some found is inscribed the name of the maker, and the situation they occupied. Where strength was required, over the joint was soldered a capping or ridge, hooped round with narrow cuttings of lead.

Pliny gives us (lib. xxxiii. cap. 30.), the method adopted for soldering the different metals; for gold, borax was used; for iron potter's clay (argilla); alum for brass; resin for lead; and in lib. xxxiv. cap. 48., the same writer tells us that tin is used as a compound to solder conduit pipes, and that the best common black lead, beaten with hammers into sheets for the making of the conduit pipes, was brought from Britain, where it was found on the surface of the ground in great abundance.

To stop the water in the pipe, or to turn it on, a metal cock was used, and many have been found, similar in their construction to those of modern date. Vessels resembling a deep pan of lead are met with, supposed to be for the purpose of measuring off a certain quantity of water.

Pipes of earthenware or terra cotta, called tubuli fictiles, are found in the walls of the baths and Coliseum of various diameters, none less than two fingers or digits, which was required to prevent any accumulation of deposit.

Canales lignei, or wooden pipes, were common in ordinary structures, on account of their economy. Piscina and cisterns were differently constructed for the reception of water: that called the Sette Sale, which served the baths of Titus, is one of the most perfect.

The Sette Sale, where the water was collected for the supply of the baths of Titus, contains nine large reservoirs; it is situated on the Esquiline Hill, in a lonely vineyard near the Palombara. By some writers it is assumed, that the quantity of water they contained

was not needed for the baths, but was intended to supply the arena of the Coliseum, when converted into a naumachia. The walls are solidly built above and below, and all the arches and vaults well turned; the outer wall is buttressed up, and the spaces between formed into hemispherical recesses. The stucco which has lined the walls is encrusted with a tartareous deposit, similar to what we find in the channels of the aqueducts, and the Piscina mirabile at Baiæ, and is so hard that it bears a polish equal to marble. The

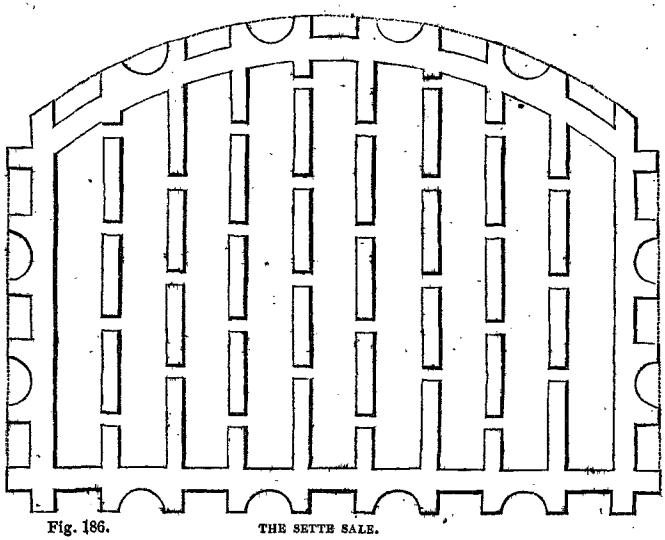


Fig. 186. THE SETTE SALE.

various communications between these halls are set out with great regularity, and standing within either, looking diagonally, a fine effect is obtained.

Piscina were intended for the same purpose as our cisterns, and by Frontinus they are designated *Limaria* when they were used for allowing water to deposit its impurities; such a piscina remains on the Latian Way, built in the manner already alluded to: the water flowing in and out of apertures made at right angles with each other. When a reservoir was covered by an arch, it was termed *contectis piscinis*; such received the waters of most of the aqueducts, and kept them from any influence that the sun's power might produce; when left exposed, vegetable matter would form on the surface, and render the water unwholesome. Frontinus describes a variety of arrangements to keep water pure, and in a piscina near the Latian Way are three divisions, which formed a perfect system of filtration; from the galleries above it could be drawn out in any state of purity, and every precaution was

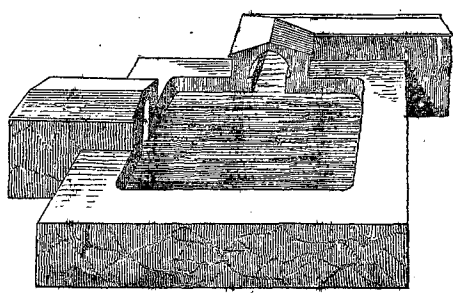


Fig. 187. LIMARIA.

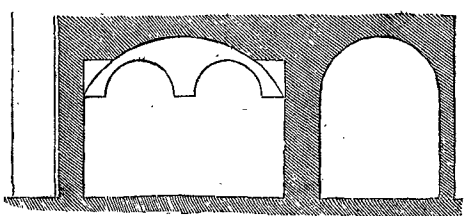
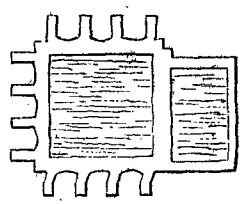


Fig. 188. CONTECTIS PISCINIS.



PLAN.

taken to provide means to cleanse at proper times each division; these were sometimes called conceptacula, and had considerable sums of money expended upon them. Sextus Julius Frontinus, who flourished in the time of Vespasian, was of a patrician family; Tacitus mentions that he was prætor of Rome, A.D. 70. We find that he held the office of consul three times, and that during the expedition to Britain, he was the proconsul; he was appointed by Nero to superintend the Roman aqueducts, and during the period he filled that office, for the benefit of his successors, he compiled the work, "De Aquæductibus Urbis Romæ," which contains an account of the aqueducts built in his time, as well as the names of all the waters brought to Rome, and by what consuls, from the foundation of the city; from what places and the miles distant; what distance they ran under ground, how much above over arches; their height, their breadth, their laying out, how much without, as well as within the city; the quantity of water delivered to each region by measure; the number of public reservoirs, as well as private; what was effected at the charge of the public, and what of private individuals; the quantity brought from lakes; and also the penalties imposed on contumacious persons by decrees of the senate, and by the commands of the emperor.

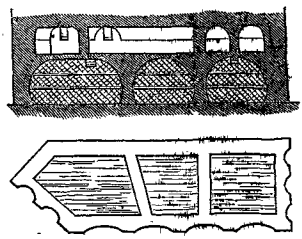


Fig. 189. FILTER.

For 440 years after the foundation of the city, the Romans were content to use the water drawn from the Tiber, or from wells and springs; many of the latter were supposed to be under the protection of deities.

The Aqua Tepula was conducted to Rome 126 years before Christ, and took its source on the borders of the Latian Way, from some springs which communicated with the Anio; its length was 2000 Roman paces.

The Aqua Julia was conducted to Rome in the days of Julius Cæsar, by Agrippa; a separate canal being added for this purpose to those of Tepula and Marcia. Its length was

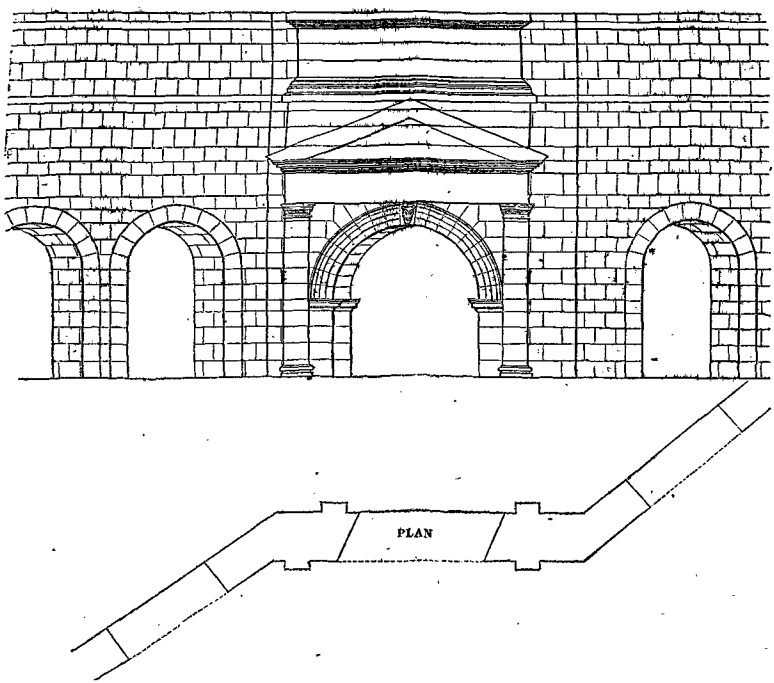


Fig. 190. AQUA JULIA AND TEPULA.

15,126 paces, 7000 of which were above ground, and 6472 on arches. Agrippa at his own expense also repaired the two which were first constructed and found out of order.

The Anio Vetus, about the year 481 from the foundation of the city, was commenced by M. Curius Dentatus, and the expenses defrayed by the spoils taken from Pyrrhus. The

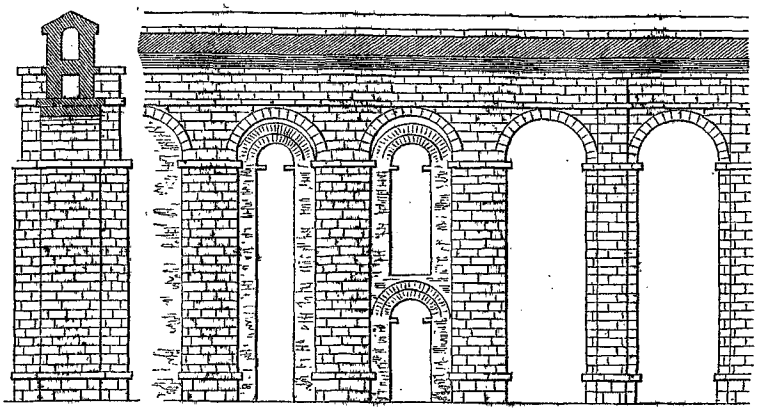


Fig. 191. VETUS AND CLAUDIA.

water was drawn from the Anio, above Tivoli, and the whole work was completed some time after the death of Dentatus, by his successor F. Flaccus. The total length of this aqueduct was 43,000 Roman paces, 221 of which were subterranean.

These two aqueducts in the year 608 from the foundation of the city needing considerable repairs, the Prætor Marius was directed to perform them, and to conduct a further supply from the neighbourhood of Subiaco, situated among the mountains 20 miles beyond Tivoli; the water of the Anio was there found in a purer state, and less contaminated with earthy matter. The length of this aqueduct was 61,710 Roman paces, 7463 above ground, and the remainder 54,247 subterranean. Where streams or valleys were crossed, arches were constructed which measured 463 paces.

The Aqua Appia, was the first brought to Rome, in the consulship of Valerius Maximus and P. Decius, in the year of Rome, 442. Appius Claudius directed this work during the time that Crassus was censor. This aqueduct commenced in Agro Lucullano, on the Prænestine Way, between the sixth and eighth mile stone, turning on the left 780 paces; its length from its head to the Salinas, at the Trigemenian gate, was 11,190 paces. It was conducted under ground for 11,130 paces, and the whole was arched over. Above ground it was carried for a distance of 60 paces, (but of this no traces now remain,) to the Capuan gate, where it united with the old Anio, at the confines of the gardens of Torquatianus.

The Aqua Virgo was introduced a few years afterwards, and some portions of it may be traced, crossing the three roads, which lead from the gates of Lorenzo, Pia, and Salara.

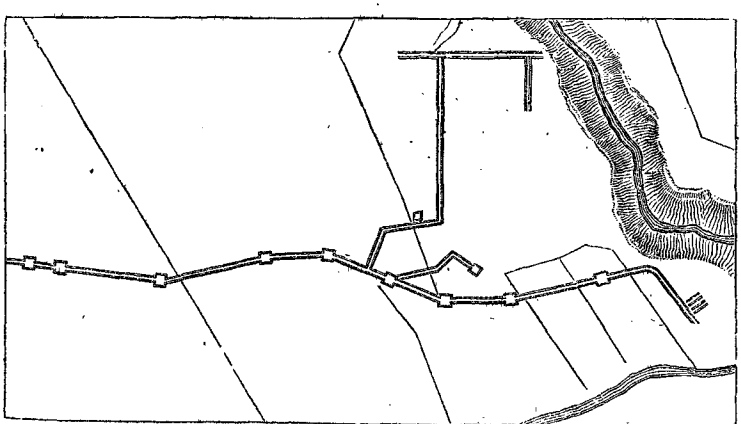


Fig. 192. AQUA VIRGO.

It was 14,105 paces in length, 12,865 underground, 1240 above. and 700 on arches, some of which were of great beauty.

The plan, elevation, and section, is from the work of Alexander Donatus, as it existed in his time.

This aqueduct had its commencement on the Via Collatina, about eight miles from the city.

The covered piscina, situated near the Pincian Hill, has two stories, and is a curious and perfect example of a part of the aqueduct; these cisterns in all probability were so named from having become receptacles for small fish. The conceptacula was the vaulted cistern, covered in a manner to protect the water from the sun's influence, which was preferable to the open reservoir or limaria. The water here entered at the top of one alley and descended by the other to the lower compartments, where it deposited the earthy matter it held. The contents of this piscina were accurately known, and the water could always be let out in any given quantity.

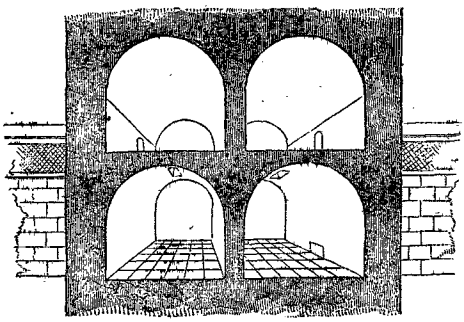


Fig. 193. CONCEPTACULA, AQUA VIRGINE.

The plan and elevation of the stairs which conduct above are well contrived for the access of the superintendents to the passages above.

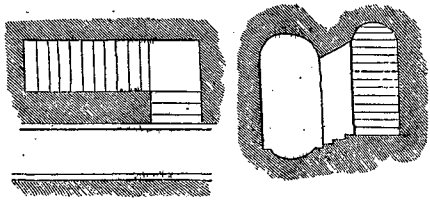


Fig. 194. PLAN. SECTION OF STAIRS.

The arches which decorate some portion of this aqueduct are not only well proportioned, but receive further embellishment from a regular order of Corinthian columns: where the passage is preserved through the line, the elevation is increased by an additional height. The section at the side shows the channel for the stream, which flowed in the attic, built above the order, covered in by a vault carefully worked and well tied together: here every precaution seems to have been taken to guard against leakage, which, if it ever happened, would be immediately discovered, by the pouring out of the water at the defective place; and along the whole line of aqueduct, materials were deposited, that there might be no delay in the work; there would be also less to perform than to take up a whole length of mains laid under a solid and hard pavement, rendered impassable during the progress. Such an inconvenience in crowded streets, the Romans wisely avoided, and continued to prefer the system of raised aqueducts to those buried in vaults under ground.

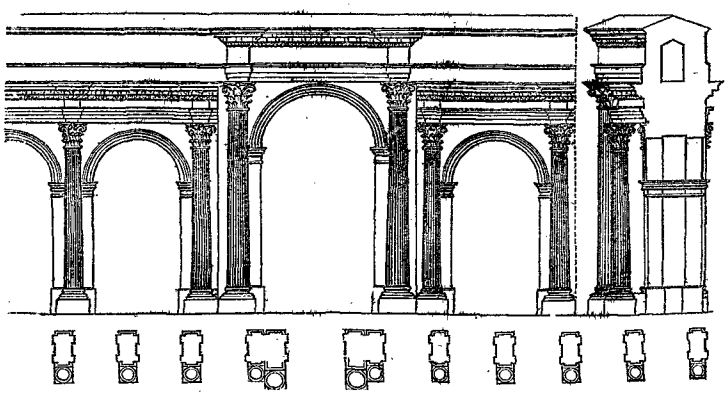


Fig. 195. AQUA VIRGINE.

The castellum of Aqua Julia is situated near the Porta Esquilina; in it we can trace the triple immissarium from which the waters were distributed. The castellum (Vitruvius, lib. viii. cap. 7.) or reservoir, constructed near the walls of the city, had a triple cistern attached to it to receive the water. Three conduits, of equal dimensions, were connected in such a manner, that when the water was more than necessary for the supply of the outer,

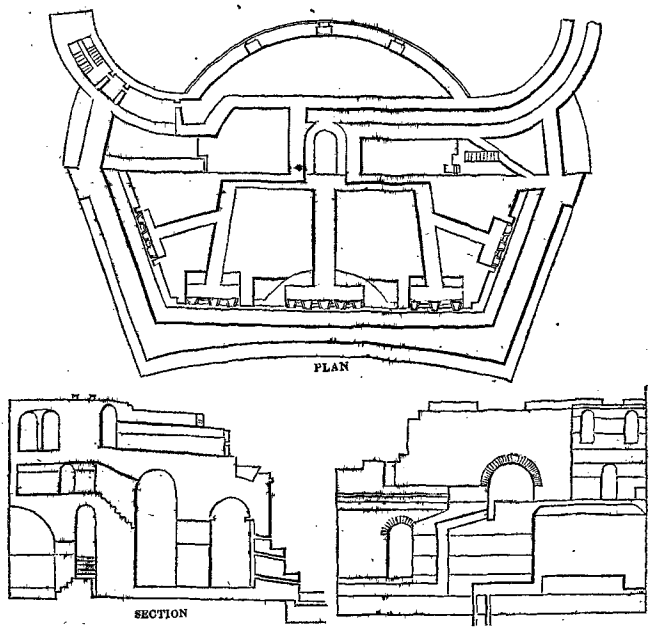


Fig. 196. CASTELLUM AQUA JULIA.

it was discharged into that of the middle, which served all the pipes of the public fountains: one of the mains supplied the baths, the other the private houses. The object of this contrivance was to provide first for the public wants, then the baths, and afterwards private individuals.

At the end of each of these three conduits was a receptacle (receptaculum), from whence the general distribution was made; at the sides were two others (caducæ) to take off any superabundant quantity. By such an arrangement the various supplies were regulated with the greatest nicety. The total width of this castellum is 115 feet; and the plan and sections show its general arrangement, its staircases, passages, and receptacles for the water. No expense was spared in the construction of these stupendous edifices, which, attached to the numerous aqueducts of Rome, must have resembled palaces. Built of squared stone, and lined with brick coated with a fine cement, every precaution was taken to prevent leakage or infiltration. The several conduits and pipes were provided with valves and corks for shutting off or turning on a supply to any direction. Here the superintendant could direct the flow of water to the several localities in his neighbourhood, without going into the castellum: he could also judge of the quantity discharged in each direction, by the simple instruments he was provided with: experience soon taught him what quantity flowed through the respective apertures, and he always knew, by guaging the several cisterns or reservoirs, what had flowed out. A constant flow from the aqueduct enabled him at the castellum to regulate its distribution, and without great arrangement, when the time came for supplying the numerous baths, there would have been found a deficiency: there needed some precautions to prevent this.

As the waters brought by these several conduits deposited a considerable quantity of earthy matter, it was necessary that the castellum which received it should be provided with conveniences, by which all the silt that accumulated could be readily removed. For this purpose chambers were attached to the several cisterns, where the water was not disturbed by the efflux or letting it out, and from them the deposit was washed, by either letting it off into the public sewers, or removing it by manual labour. In some of the cisterns or reservoirs discovered, the bottom was made with a considerable fall or inclination

towards a pit sunk in the middle, or like a shallow basin, with a circular hole in the centre, through which might be scoured out all the accumulations of sand or lime deposited; these holes were simply closed or secured by a plug, or by a hard stone in the form of the frustum of a cone.

The arch which supports the triple aqueduct of Julia, Tepula, and Martia shows the last-mentioned water conducted through the lowest channel in the section, and that of Julia in the uppermost: it is situated near the Porta Esquilina, and on it is the following inscription: —

IMP. CAES. DIVI JULI F. AUGVSTVS
PONTIFEX MAXIMVS COS. XI.
TRIBVNIC. POTESTAT. XIX. IMP. XIII.
RIVOS AQVARVM OMNIVM REFECIT.

Underneath is another inscription, showing when it was repaired.

IMP. TITVS CAESAR DIVI F. VESPASIANVS AVGVST. PONTIF. MAX.
TRIBVNICIAE POTESTAT. IX. IMP. XV. CENS. COS. VII. DESIGN. VIII.
RIVOM AQVAE MARCIAE VETVSTATE DILAPSVM REFECIT
ET AQVAM QVAE IN VSV ESSE DESIDERAT. REDVXIT.

Three streams, conducted by artificial channels one over the other, and differing in quality, required particular care that they did not leak one into the other, and that the better should not be deteriorated by communicating with that which differed from it in salubrity and clearness: we consequently find that the channel for each is based upon a thick stone, passing into the sides of the aqueduct, which is covered with tiles and a coat of cement with the greatest care: the only chance of any rupture or crack would arise from a settlement of a division of the arcade, which would immediately be discovered by the leakage, and would speedily be restored. Doors from the outsides admitted the attendants occasionally to examine the several conduits; and it was the duty of the supervisors and sub-engineers to report constantly upon their efficiency and condition.

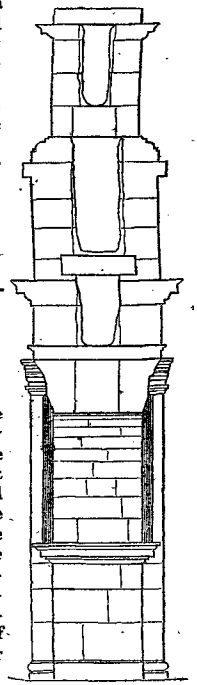


Fig. 197. SECTION OF AQUEDUCT OF AQUA JULIA TEPULA, AND MARCIA.

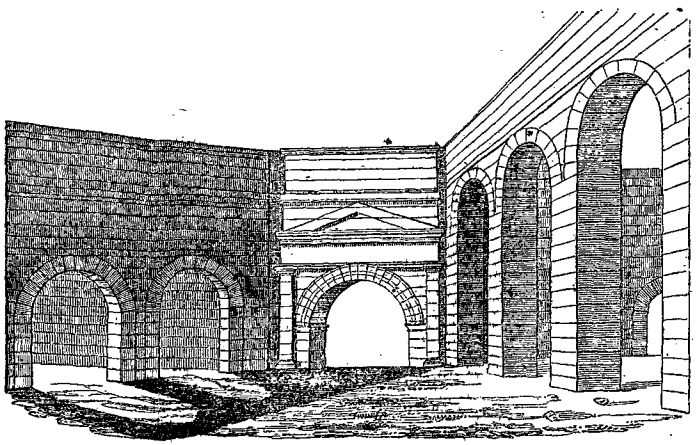


Fig. 198. AQUA JULIA, TEPULA, AND MARCIA.

And below this, immediately above the middle arch upon the architrave which supports the cornice, is cut another.

IMP. CAES. M. AURELIUS ANTONINUS PIUS FELIX AUG. PARTHIC MAXIM.
BRIT. MAXIMUS PONTIFEX MAXIMUS.
AQUAM MARCIAM VARIIS CASIBUS IMPEDITAM PURGATO FONTE EXCISIS ET PERFORATIS
MONTIBUS RESTITUTA FORMA ADQUISITO ETIAM FONTE NOVO ANTONINIANO
IN SACRAM URBEM SUAM PERDUCENDAM CURAVIT.

Seven aqueducts were sufficient to supply Rome until the time of Caligula, when two others were commenced, which were finished by the emperor Claudius: these were —

Aqua Claudia. — Few aqueducts exhibit greater beauty of construction or design, and

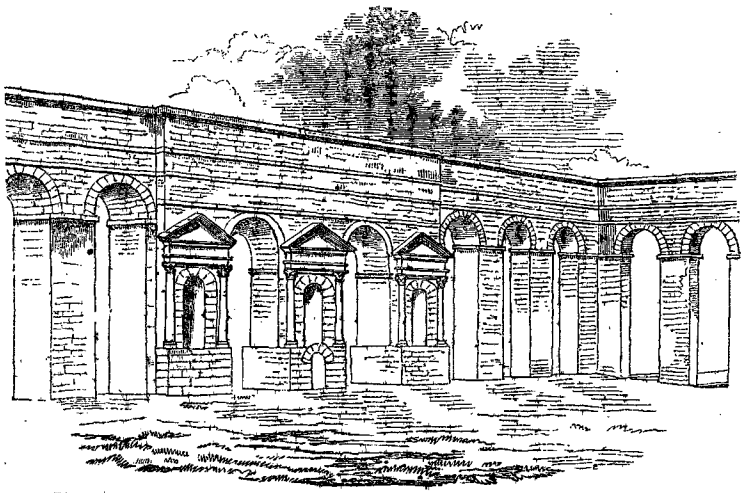


Fig. 199. AQUA CLAUDIA AND ANIO NOVUS.

what remains is a monument of the munificence of the emperor: it was extended from the Porta Maggiore to the brink of the Cælian Hill by Nero.

When we examine this structure throughout its entire length of nearly 50 miles, we cannot allow the Roman engineers who constructed it to have been ignorant of hydrostatics. After the source of the springs had been discovered, to have conducted the water by a regular fall to the castellum, and then distribute it to the several portions of the city, could not be accomplished without a thorough knowledge of the levels of the country through which the aqueduct was to pass: one regular fall was maintained throughout, that the water might not be either unnecessarily agitated or retarded: and it would be far more difficult to regulate such a fall on a lofty structure of arches, than in a system of pipes laid under ground. Such knowledge indicates that the Roman engineers were profoundly instructed in the sciences, and

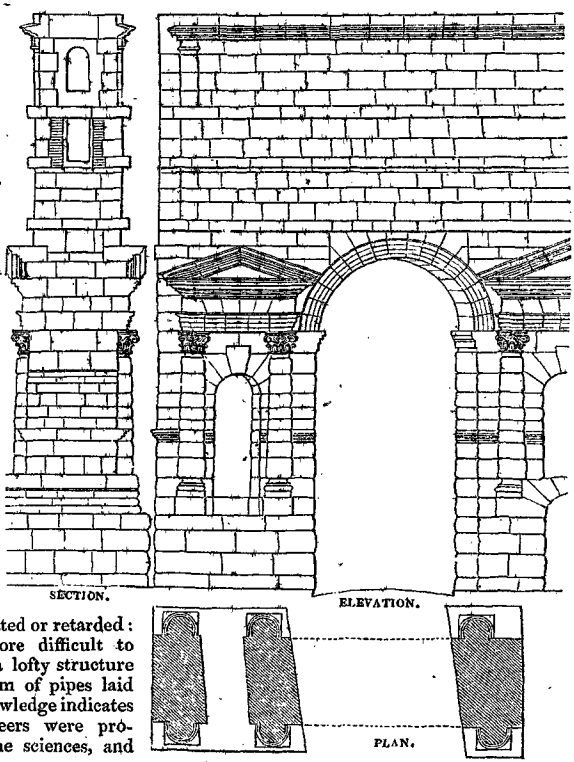


Fig. 200. AQUA CLAUDIA AND ANIO NOVUS.

thoroughly understood the properties of running water. This aqueduct received two streams, which flowed from near the *Via Sublaceni*, a road which follows the valley of the Anio, above Tivoli. Its total length was 46,406 Roman paces, 36,230 subterranean, and 10,176 on arches.

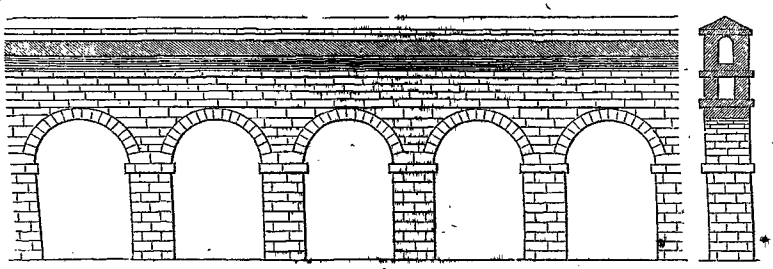


Fig. 201. AQUA CLAUDIA AND NOVUS.

The other was the *Anio Novus*, the most considerable and curious in its construction. It was in length 58,700 Roman paces, 49,300 under ground, 9400 above, and 6491 carried on arches, some of which exceed in height 100 feet. Before the water was admitted into this aqueduct, it passed through a reservoir, where the sediment was collected. Both these aqueducts, after passing on arches and under ground, were united, although the waters were kept separate.

The Tiber, at Rome, was considered to be 91½ feet above the level of the Mediterranean; and the various heights above the level of the Tiber there that these several aqueducts delivered their water may be thus stated.

	Feet.
The Anio Novus was above the level of the Tiber	158·88
The Aqua Claudia	148·9
The Aqua Julia	129·4
The Aqua Marcia	125·4
The Anio Vetus	82·5
The Aqua Virgo	34·2
The Aqua Appia	27·4

The nine aqueducts which supplied Rome with water in the time of Frontinus are stated to have furnished a quantity as follows:—

The Aqua Appia	
The Anio Vetus	4398 quinariæ
The Aqua Marcia	4690
The Aqua Tepula	
The Aqua Julia	1398
The Aqua Virgo	2524
The Aqua Alsietina	14018
The Aqua Claudia	4607
The Anio Novus	4738

For construction and architectural arrangement the most beautiful was the Aqua Claudia, built entirely of squared stone; that of Marcia, which ran almost parallel with it, had its arches 16 feet span, constructed of different kinds of stone, red, brown, and yellow; the waters were conducted in canals, one above the other, and the arches in many places were more than 70 feet in height. Others were of brick and marble, subject to dilapidations, and cost vast sums to repair.

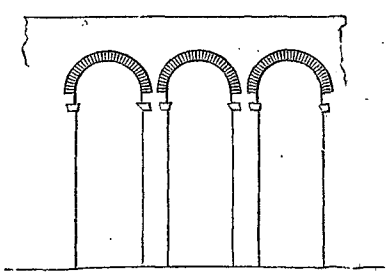
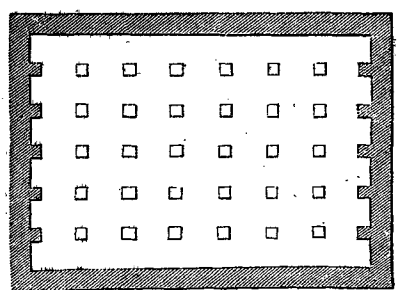


Fig. 202. SECTION.



PLAN OF RESERVOIR.

The reservoirs, attached to most of the aqueducts for cleansing and filtering the waters, were constructed and attended to with the greatest care. The emperor Nerva formed many deep reservoirs by the sides of the aqueducts, to collect the sediment in its passage, and also ordered that the Aqua Marcia should not be used for any other purposes but that of beverage, it being the coolest as well as most transparent of the waters brought to Rome.

When these structures required repair in the first instance slaves were employed, 240 being engaged by Agrippa for that purpose. In the time of Claudius, regular fountaineers were appointed, to the number of 460 persons, distributed into overlookers, keepers of the castellum, stone-cutters, masons, plasterers, stuccoers, and others. The works were conducted in the winter, it being thought that the heat of summer would occasion the masonry to dry too fast for its solidity.

In Rome every house had its fountain, and the water laid on, for the use of the inhabitants, and it was not considered that a dwelling was fit to receive a tenant, however humble his lot, unless it was provided with an abundant supply of water—an instance of consideration worthy the imitation of modern times.

Aqua Alsietina, in length 22,172 paces, was brought by Augustus to Rome; the water was of a quality only fitted for the purposes of irrigation, being considered unwholesome to drink. 358 arches formed a part of its construction.

Aqua Aniene nuovo and *Claudia* are carried over the Porta Maggiore on two stone arches, highly decorated; the water of the Anio Novus flows above that of Claudia, as indicated in the section.

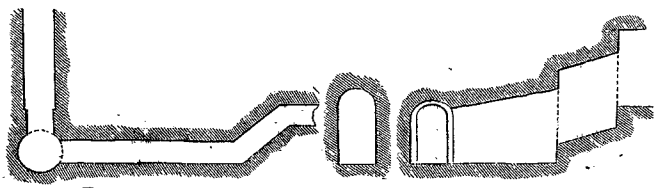


Fig. 203. PLAN. SECTION.

The front, which is situated on the Via Prænestina and Labicana, exhibits the following three inscriptions.

TI. CLAUDIUS DRUSI F. CAISAR AUGUSTUS GERMANICUS PONTIF. MAXIM. TRIBUNICIA POTESTATE XII. COS. V. IMPERATOR XXVII. PATER PATRIAE QUAS CLAUDIAM EX FONTIBVS QUI VOCABANTUR CAERVLEUS ET CURTIUS MILLIARIO XXXXV. ITEM ANIENEM NOVUM A MILLIARIO LXII. SUA IMPENSA IN URBEM PERDUCENDAS CURAVIT.

IMP. CAISAR VESPASIANUS AUGUST. PONTIF. MAX. TRIB. POT. II. IMP. VI. COS. III. DESIG. IIII. P.P. AQUAS CURTIUM ET CAERULEAM. PERDUCTAS A DIVO CLAUDIO ET POSTEA INTERMISSAS DILAPSASQUE PER ANNOS NOVEM SUA IMPENSA URBI RESTITUIT.

IMP. T. CAISAR DIVI F. VESPASIANUS AUGUSTUS PONTIFEX MAXIMUS. TRIBUNIC. POTESTATE X. IMPERATOR XVII. PATER PATRIAE CENSOR COS. VIII. AQUAS CURTIUM ET CAERVLEAM PERDUCTAS A DIVO CLAUDIO ET POSTEA A DIVO VESPASIANO PATRE SUO URBI RESTITUTAS CUM A CAPITE AQUARUM A SOLO VETUSTATE DILAPSAE ESSENT NOVA FORMA REDUCENDAS SUA IMPENSA CURAVIT.

Alexander Severus embellished Rome with many stately buildings and magnificent porticoes. Near Labicana, four miles from the city, are the remains of an aqueduct which

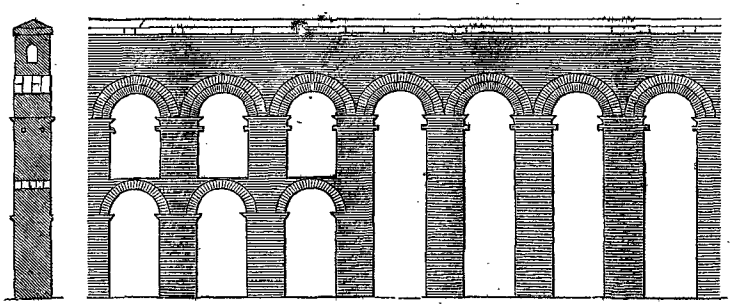


Fig. 204. ALEXANDRINA.

conveyed the water called Alexandrina to Rome. This emperor was murdered A. D. 235, and left this fine specimen of construction for our admiration. He was accomplished, fond

of literature, moderate at his table, and partial to men of genius, from amongst whom Ulpian was selected to be his constant companion.

The Aqueduct at Nismes, or the Pont du Gard, was, perhaps, the earliest constructed by the Romans out of Italy, and is supposed to have been executed by Agrippa, who was governor

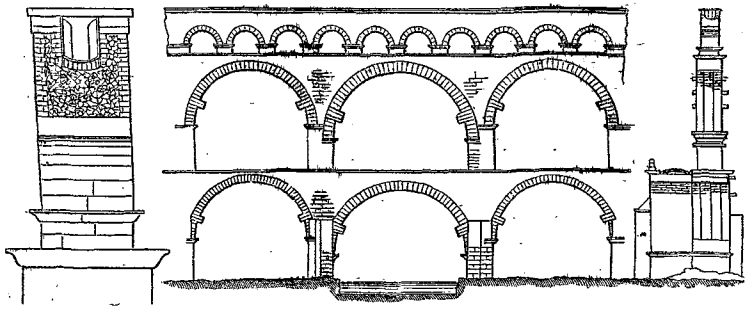


Fig. 205. PONT DU GARD.

of that city in the time of Augustus, and declared curator perpetuus aquarum. Its perfect arrangement affords us the best means of judging of such works.

It has three tiers of arches, one above the other; the lowest, under which the river Gardon passes, is composed of six arches, the second of eleven, and the upper or third tier of thirty-five, besides two openings made at the side, at the time of the invasion of Gaul. The arches are semicircular, and rest upon piers more or less elevated. Above the upper row was the conduit for the water, which passed the valley of the Gardon at a height of more than 157 feet above the river below.

The length of this splendid monument at the level of the string course surmounting the first tier is 562 feet, and at the level of the second string course 885 feet; it is nearly the same length above the crowning stones of the aqueduct, between the extremities where broken down.

The total height is 161 feet, viz. 66 feet for the first story from the bed of the river to the first string course, the same to the second string course, and 29 feet to the top of the stones which cover it. The divisions of the arches and piers of the first and second stories correspond; the largest arch of the first story, under which, when there is little water in it, it generally passes, is the centre of the monument, and the second from the left bank of the Gardon. On the first and second story, on each side, are arches of a smaller space, which are succeeded by others still less. The difference in the span of these arches, and their all being semicircular, obliged their springing to commence at different levels, which has a singular effect. The large arch through which the river passes is 80 feet 5 inches in diameter; the three on the right side are 63 feet, and the smaller are 51 feet. All the arches of the upper story are equal in span, 15 feet 9 inches: their piers vary in width, and do not come immediately over those of the two stories below; consequently, in this tier there is no symmetry maintained with those beneath them, nor are the perpendiculars kept.

The thickness of the Pont du Gard, from the face of one side to that of the other, is at the first story 20 feet 9 inches, at the second story 15 feet, at the third 11 feet 9 inches. Each story forms a considerable set-off, three feet nearly on each side of the first story, and 1 foot 6 inches at the second, where the string course or cymatium was increased a little more than a foot in its projection, to allow foot passengers to traverse the valley with more facility.

The lower piers are strengthened and protected by buttresses of a triangular plan, which directed the waters of the valley in time of floods. The construction of the Pont du Gard exhibits great skill; the stones are all laid according to their natural beds in the quarry, and their dimensions are considerable: they were brought from the neighbourhood, on the left bank of the river, and are of the same quality as those employed in the amphitheatre at Nismes. Corbels or projecting stones are left in various parts, for the purpose of supporting the centres and scaffolding, which were not removed, that they might be serviceable for after repairs.

The foundations were established upon a rock 6 feet above the bed of the river, and the thickness of the piers is formed of only two or three stones of large dimensions. The courses are in general 2 feet in height. The key-stone of the large arch is 5 feet 3 inches, and that of the others 5 feet in depth; those of the arches of the upper story 2 feet 7 inches.

The lower arches are formed of four separate rings in their soffites, those of the range above of three, and those of the upper or smaller range of single rings or courses of voussoirs;

this kind of construction is unique; the voussoirs seem to be carried side by side, and the soffites of the arches exhibit the joints not broken, but continuing round in one line. The thickness of the arch consists of three distinct arches not tied or bonded together.

The whole is of freestone, from the foundations to the third course above the cymatium, which covers the piers of the third story. Moellon or rubble was employed for the filling in of the piers, spandrills, and haunches, of the first and second stories.

The stones are laid without cement, and owe their solidity to the weight of each block, and the nicety observed in the working of their beds and joints. Each stone was dropped into its place by means of the lewis, the holes for the insertion of which are still seen exactly placed over the centre of gravity of each. The work above the small arches of the third story is of masonry filled in with rubble work: here a considerable quantity of cement is used, which has become as hard as the stone itself, forming one impermeable mass, and preventing any filtration, which would, if suffered, have been detrimental to the structure.

The channel for the water is placed between two walls of masonry, 2 feet 9 inches thick; the bottom has an inverted arch, which with the walls are covered with a cement 2 inches in thickness, composed of fine sand, powdered brick and quick-lime. Its strength is equal to that of the hardest stone, and there is no apparent change in it, since it was first laid on. This layer of cement is covered with a fine mastic, very thin, and of a deep red colour, laid on with a brush, giving the whole a face as smooth as highly polished marble.

The waters of the Eure and Airan were conducted along this course, which was 4 feet in width, and 4 feet 9 inches in height. The walls are of moellon or rubble, and had over them a covering or slab, 2 feet 6 inches in height, formed of two courses of freestone projecting 2 feet; over these were laid slabs of freestone, which covered in the aqueduct, 12 feet in length, and 3 feet 3 inches in width, projecting over the walls below 9 inches. The fall given to the water is four-hundredths of a foot for every hundred feet, throughout the entire length of the aqueduct, which brought the waters to the inhabitants of Nismes, from the sources of the Eure and Airan in the valley of Uzes; after these rivers have supplied many mills, they fall into the Gardon, near the Pont du Gard.

Several portions of the two aqueducts which conveyed their waters respectively to the great aqueduct still remain, between Uzes and the village of S. Maximin.

The commencement of the aqueduct was to the south of S. Maximin; it followed all the sinuosities of the hill, so that the level was always maintained; it was entirely underground, and often cut in the rock itself. The Romans constructed small bridges over the rivulets, which were permitted to pursue their course to the Gardon. One of these, thrown across the cascade of the Bord Negré, remains. After having passed the Château d'Argellies the side of the hill is lower, and the summit is below the level of the waters, conducted to this point; here the aqueduct is carried on a series of arches, similar to those of the upper part of the Pont du Gard, with which they unite, passing behind the village of Vers, and describing on their plan considerable bendings, that they may follow the crest of the hill, which precaution was necessary, to economise the height of the piers. Thus the waters of the Eure and Airan arrived at the Pont du Gard by a circuitous flow of 50,855 feet; after it had passed the Pont du Gard, the aqueduct was lost in the sides of the mountain as far as Lafoux; it then reappeared, and was carried on arches more or less elevated across the gorges met with in its passage, some of which remain. It was then carried on the eastern side of the hill, behind St. Bonnet, under the village of Sarnhac, and crossed the great road to Nismes near Besonce, to arrive at the mountain of St. Gervasy, which it followed as far as Nismes. The whole distance from the Pont du Gard is 83,665 feet: whence it results that the total length of the aqueduct between the extreme points was 134,515 feet. The relations of both Vitruvius and Pliny on the construction of aqueducts, the engineer here finds carried into effect in the most admirable manner, and he must be convinced that the knowledge possessed by the ancients of the laws of hydrodynamics was far greater than they have received credit for. If their writers have not handed down to us the calculations made previous to the commencement of these vast and laborious undertakings, the works show practically their engineers thoroughly understood the art of levelling, and the laws by which water in its course was governed: though the fall given to the slope of the channel of this aqueduct is but small, it is regular throughout, and from the masterly manner in which it is conducted, we cannot but give the constructors the credit of having understood thoroughly the nature and properties attendant upon running water, and that they must have observed and studied the slopes and beds of the rivulets and larger streams before they could have arrived at the knowledge displayed in these surprising monuments; as much care was required, or perhaps more, to set out one of these water conduits, than is demanded for a modern railway. We find the principles to perform both nearly similar, the locomotive, in one case, is to be moved along a level or inclined plane at a certain angle, while the water is to keep one uniform and constant course; both in mountainous districts must be conducted over valleys on artificial constructions, and along the sides of steep hills, and this must be performed without creating any abrupt turns or angles. In drawing a comparison between the experience of the men employed in engineering works in times past and at the

present day, the aqueduct and railroad might be taken as a fair test of their ability; to effect the one is as difficult as the other, and the same kind of talent is required in both; he who could perform the one might safely be entrusted with the other. If this opinion is correct, we ought not to be satisfied that during the last two thousand years we have made sufficient progress, and the historian may, perhaps, be induced to say we had not yet arrived at the excellence attained in former times. When the writer visited this splendid Roman work in the year 1817, it was about to receive a considerable repair: no monument is more deserving of being upheld than the Pont du Gard; it is an evidence of the talent and skill of the Roman engineers in their best days, and worthy of being studied by all who have the conducting of water to a great and important city.

Aqueduct of Volsci, an ancient city of Etruria, the date of which is not accurately ascertained, though its manner of construction indicates the period of the empire, of which it is a splendid specimen.

Fig. 206. AQUEDUCT NEAR VOLSCI.

Modern writers wonder why aqueducts were built in preference to the humble and ordinary method of conveyance of water in pipes, and condemn Sextus V., Nicholas V., and Paul V., who during their sovereignty as Popes used similar means to bring three noble streams of water into Rome. In the first place, any metal pipes laid across the Campagna or marshy land in the neighbourhood of that city, would not only have perished ultimately from the abundance of carbonic acid contained in the waters of the soil, but this dissolving the lead or iron would poison all the inhabitants: in the next, the pipes would have been more costly than masses of masonry, if the bore was sufficient to conduct the quantities which the arched aqueducts were enabled to do. By taking the levels accurately at first, and allowing the proper fall throughout, a regular supply was maintained, and the water, perfectly pure throughout its whole course, was delivered into castelli, or reservoirs at a height above the level of the city which rendered any mechanical power unnecessary for its elevation: it could from them be distributed to the baths, fountains, and private houses, by simply opening the sluices at particular hours appointed for the purpose. The ancient aqueducts for nearly 2000 years have conveyed running streams constantly, and if an estimate was made of the cost of their first construction in stone or brick, after the Roman manner, and another upon our system of pipes, their wear and tear, with the daily and hourly expense of steam-engine-power to raise the water, the balance would be found greatly in favour of the ancient method. The purity of the water and its abundance, which could keep hundreds of fountains of the imperial city, and still does, constantly playing, is another reason in their favour.

Aqueduct at Lyons. Augustus, Tiberius, and Claudius, all contributed to the embellishment of this ancient town, then called Lugdunum. A palace erected by the latter emperor in the

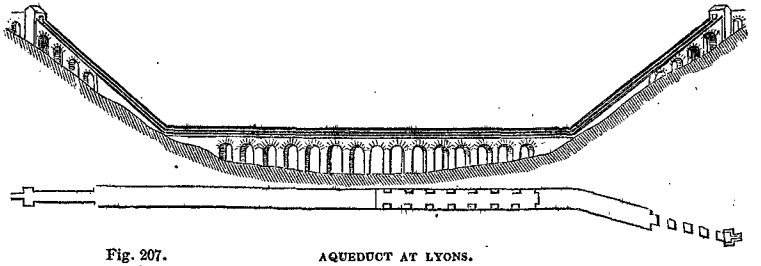


Fig. 207. AQUEDUCT AT LYONS.

highest part of the city requiring to be supplied with water, an aqueduct was constructed with arches built of rubble stone, faced with opus reticulatum. The manner in which this

work was performed was as follows: — A level pavement was formed of brick, on which was raised a frame or caissoon of timber planks; against the sides of this, squared stones were laid in regular courses, and their interior filled in with rubble, in a dry state, after which a grouting of liquid cement was poured in to consolidate the whole. Lime, fine gravel, or sand, mixed with a due proportion of water formed this grouting; after a sufficient time had been allowed for the work to consolidate, the caissoon was mounted upon another course or layer of tiles, and similar operations to the first took place.

The bricks or tiles used are 1 foot 9 inches in length, 12 inches in breadth, and an inch and a half in thickness.

The whole of the water conduit was coated with cement; at the bottom its thickness was 6 inches, at the sides an inch and a half: 24 inches from the bottom of the canal, at every 30 inches distance, iron ties were inserted to hold the side walls together, and prevent their being pressed outwards.

The three aqueducts of the ancient Lugdunum were traced for many miles to the source of the waters they conducted, by M. Delorme, who, in 1759, gave to the séance de l'Académie an account of his researches. The Mont de Pile derived its supply from the river Gierre and some smaller springs in its vicinity. These waters having been conducted over eight bridges, across the valley where the ninth was situated, the syphon was carried over. The valley at the foot of the heights of Soncieu is very deep, and where the aqueduct crosses, was a large reservoir, constructed on the south side of the river Garon.

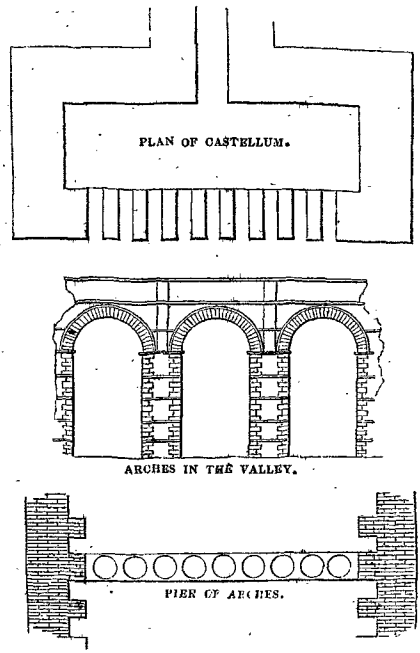


Fig. 208. LYONS.

Here we have an example showing us that the Romans well knew, when water was brought down one side of a hill, how to make it rise on the other: why this plan was adopted in preference to building a series of arches, like the Pont du Gard, we are not informed; but the arrangement proves that they practically understood that water would find its level, what precautions to take to expel the air, and the advantages of a venter.

Leaden pipes of large dimensions, bedded on the sides of the valley, conducted the water to others, laid over a bridge in an inverted curve; they were then continued up the opposite sides of the valley, and delivered the water into another reservoir, of corresponding level to the one on the hill before described. The aqueduct then took the name of Chaponest, from the hill where the last reservoir was situated, and the waters were conducted underground along the west side of the village. A bridge of 90 arcades carried it to another reservoir, when it again descended into the valley in similar leaden pipes, passing over the river Baunan in an inverted curve, and again mounted to a second reservoir at St. Foi. A series of arcades conducted it to level ground, sometimes above, at others below; it continued its current till it reached the gate of St. Irenee, where was another reservoir; leaden pipes conducted it through the fosse of St. Irenee, when it mounted once more, and was discharged into another reservoir, near the Gate of Trion; in this instance the pipes were bedded in a mass of solid masonry, and not carried over a bridge.

The total length of the course of this aqueduct was 13 leagues, in which distance it had a fall of upwards of 350 feet.

The reservoir, which emitted the water at the aqueduct bridge of the Garon, was built at the top of a tower; its length was 14 feet, and its breadth 4 feet 6 inches. On the side towards the valley 9 oval holes were made, at 9 feet from the bottom, about 12 inches in height, and a little less in width; through these passed the leaden pipes, which descended into the valley, crossed over the bridge of arches, and rose on the other side in the regular and uniform curve of a great syphon. When the water reached the reservoir destined to receive it on the opposite side, it entered at the top, and was emitted at the bottom: the leaden pipes were 8 inches diameter in the clear, formed of metal of an inch in thickness, and the water in the emitting reservoir was always a foot lower than in that which received it. One

portion of the aqueduct was formed by opening a trench 5 feet wide and 10 feet deep, with a uniform fall of 12 inches for every hundred toises. The channel for the water was lined with masonry, the bottom of which was 12 inches thick; on this two walls, 18 inches in thickness, were raised to the height of 5 feet; the space between, being two feet in width, was covered by a semicircular arch, 12 inches in thickness, over which earth was laid to an average thickness of 2 feet.

At the bottom of the watercourse a coat of cement, 6 inches in depth, was laid, and the sides were coated in a similar manner, to the thickness of an inch and a half; the width between the walls being reduced to twenty-one inches. The walls were formed of small angular stones, laid in mortar, composed of coarse rough sand; the cement used for the lining was made of very fine sand, lime, and powdered brick; that employed for the first coat was of a coarser kind, the powdered brick being as large as a pea; but the lime seems to have been fresh from the kiln, and well-tempered at the time.

Where the aqueduct was tunnelled in the side of the mountain, and its watercourse was considerably below the surface, *putei* or wells were sunk, to allow the vapours which arose to disperse freely; these shafts were made at the distance of an *actus*, or 120 feet, many of which are found with their sides steined in very perfect order; they admitted light and air, and also the workmen who were required to repair any defects, or remove any deposit that might by accident accumulate within the channel. The putei must not be confounded with the columnariæ, or vent-pipes, which were perpendicular tubes, the tops of which rose considerably above the aqueduct, for the purpose of maintaining an equal pressure and ventilation throughout. Health was the consideration which caused so many contrivances to maintain the water pure; the ancients knew that pent up, and not allowed its due proportion of air, it lost that sparkling effect for which it is admired; they preferred the walled aqueducts on this account, as they delivered the water in a wholesome state.

Where the works are above ground, the walls, 2 feet in thickness, are faced with reticulated work, the size of the lozenges varying from 3 to 6 inches square, and worked without any intermediate course of brick. The arches were roofed over, to throw off the rain; and the entrance to the aqueduct was by iron doors placed to open internally. Those portions underground were approached by man-holes, brought up a little above the level of the soil, and the entrance of the water into the aqueduct was by a valve, which, sliding up and down, could be regulated at pleasure.

When the aqueduct was formed above ground, a footing of masonry 6 inches in thickness was set out, and the span of the arches varied according to their height; all were semi-

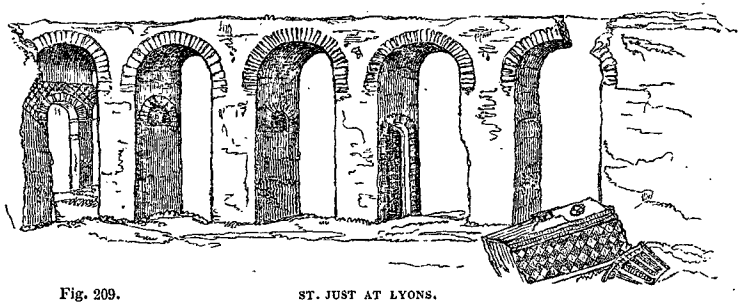


Fig. 209. ST. JUST AT LYONS.

circular, and if of 12 feet span, the piers were made equal to half, and where the arches required to be built to the height of 31 feet, the width of the opening was 15 feet 6 inches, and the piers 7 feet 9 inches; so that the piers were half the opening, and the opening or span made equal to half the height.

Where the canal for the water was formed on this portion of the aqueduct, an offset was made on each side, increasing the thickness to 6 feet.

The piers and masonry throughout are of a corresponding style, formed of small square stones, laid in a thick bed of mortar, and known as the opus reticulatum, a beautiful kind of work, described by Vitruvius in lib. ii. cap. 8.: it is, however, very subject to split, from its not having the necessary bond; its whole strength depends upon its quoins being proportioned to the space given to the reticulated division — which must always be regarded as a simple filling in. The two or three courses of tiles or stones which lay horizontally through the entire wall serve to tie on the two faces of the work, in part, but there is not that stability in a pier so constructed, as is found with either English or Flemish bond; the cement,

when excellent, makes up for this defect, but we frequently find in reticulated work openings and cracks, which prove it is not calculated to support a heavy and constant weight. At every 4 feet in height, two courses of brick bonded or tied the work together, the bricks being 2 inches in thickness, and twenty-two inches square. The quoins of the piers are formed of squared stone, but as these were not properly worked, they have been detached and created considerable injury.

The voussoirs of the arches are composed of stone, 3 inches in thickness, and an alternate one of brick; over the extrados is laid a brick, which by its projection forms a label, on this two courses of tile or brick are bedded, which continue through the whole length without projecting. On this course of double tile the water channel is built.

The valley between Soucieu and Chaponost has a depth of nearly 200 feet, and for nearly 2500 feet the water is conducted over an aqueduct composed of five stories of arches; that between Chaponost and St. Foi is nearly 300 feet in depth, has eight stories of arches, and the third valley between St. Foi and Fourvieres had three stories of arches.

Some of the leaden pipes found at the extremity, where the water entered the palace, were from 15 to 20 feet in length, and bore the marks of Tiberius Claudius Cæsar.

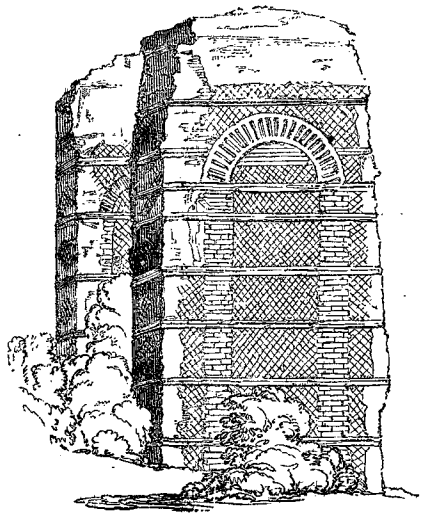


Fig. 210. PIER AT LYONS.

The Aqueduct near Frejus, called Esterelle, where it passes through the country of Gargallon, or Agreeable Valley, is a noble structure. Its piers are strengthened by buttresses, the winds of this valley being at times powerful and very destructive: the water is brought

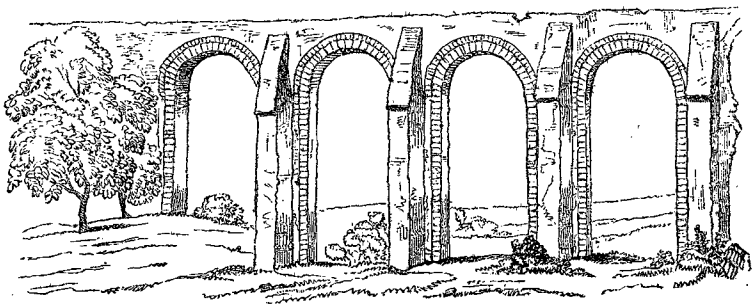


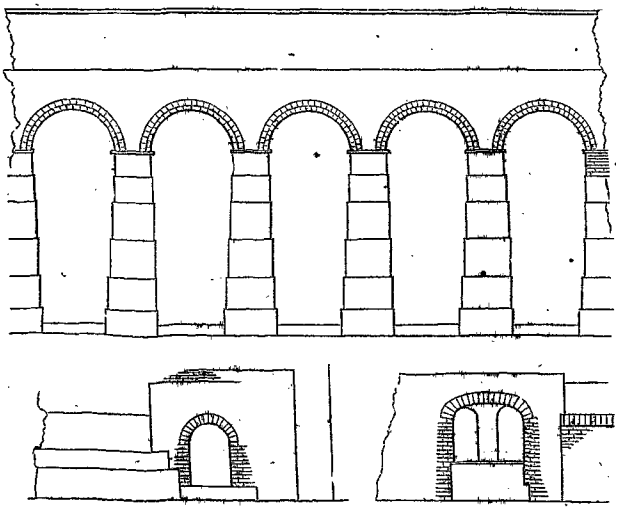
Fig. 211. ESTERELLE ARCHES.

from the river Siagne, running near Mons, 5 miles from Frejus. The country is very uneven, and full of rocks, which in many parts have been tunnelled. The whole circuit made by this aqueduct, in consequence of the difficulties presented by the country through which it passes, is more than ten leagues.

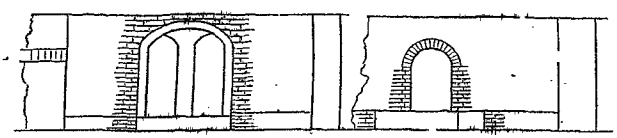
All the provinces in the south of France were as well supplied with water as Rome itself, and the various engineering works as admirably performed as in the imperial city. Rich, indeed, is this district with amphitheatres, theatres, temples, baths, and public buildings, and no one can doubt, who has travelled through this delightful district, of the progress made in the arts and civilisation at a very early period.

Aqueduct at Metz, was another beautiful piece of construction that conducted the springs found in a valley beyond Gorze, now called *les Bouillons*, for a distance of 11,373 toises, with a face of about 70 feet. They are first led through a channel 3 feet in breadth, and 6 feet deep, formed in a bed of masonry, composed of rough stones and mortar. On the interior the walls are faced with masonry in regular courses, and where the watercourse is laid against the side of the hill, an additional wall, varying in thickness from one to two feet, is

built to resist the thrust of the earth. The channel for the water is arched semicircularly, and the voussoirs are at the top 3 inches thick, and at their intrados only 2: they are generally 12 inches square.



PARTS OF CASTELLUM.



METZ.

Fig. 212.

The remains at Jouy are considerable, and are situated at about one league from Metz, in a beautiful valley, through which the Moselle flows. There are sixteen arcades, the openings unequal; six before arriving at that which forms the entrance to the village, the others are in a meadow; the aqueduct afterwards crosses the Moselle. The work is executed with small stones, in the form of bricks, laid in regular courses; and in the neighbourhood is a quarry where many of these stones remain, and the hatchets which prepared them have sometimes been found.

The erection of this aqueduct is attributed to the Roman legions at the time they were commanded by Drusus, who obtained a victory over the Germans; he was the son of Livia, and brother to the Emperor Tiberius; his monument is at Mayence, where he died at thirty years of age, in consequence of a fall from his horse.

The plan of the Castellum and of the Piscina limaria may be accurately traced, the arches and construction of which are highly ingenious.

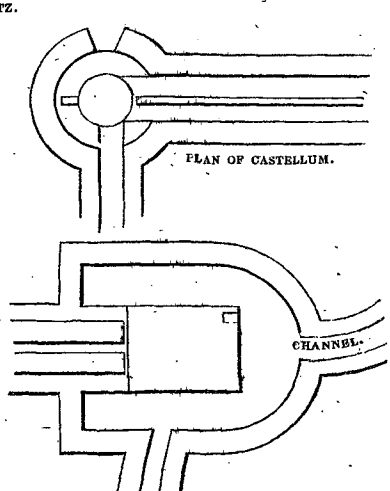


Fig. 213. PLAN OF PISCINA LIMARIA AT METZ.

The length of the series of arcades which crossed the Moselle was about 570 toises; the thickness of the piers 12 feet, but the opening of the arches, and the width of the piers, varied; these were sometimes 14, and at others 15 feet.

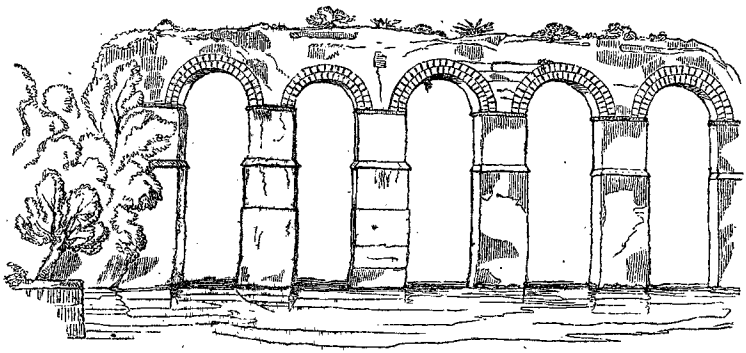


Fig. 214. JOUY.

In one part of the aqueduct was a double channel, formed by a division wall, which was considered serviceable in case of a repair being required.

The quantity of water which flowed to Metz was calculated at upwards of a thousand cubic feet per minute.

Aqueduct of Evora in Portugal, in the province of Alemtejo, was constructed, as well as a temple to Diana, by Sertorius. This town, the third of importance in the kingdom, abounded with Roman remains. The aqueduct is in good preservation, the arches are 13 feet 6 inches in span; the piers 9 feet in breadth, and 4 feet 6 inches in thickness. In some instances additional strength is given by buttresses. All the work is executed in stone, with the exception of the arches, which are in tile or brick. The castellum, of fine proportions, remains very perfect; its form is circular, 12 feet 6 inches in diameter; on the exterior are eight Ionic columns, between which are as many niches, with hemispherical heads, through one of which is an entry to the interior. Over this order is another formed of pilasters, and the chamber was covered by an hemispherical dome.

The Aqueduct at Carthage. Its ruins may be traced for a distance of fifty miles, at the village of Arriana, near Tunis; one range of arches is entire, 70 feet high, with piers 16 feet square, built of a hard durable limestone, and excellent mortar. Many of the cisterns for the reception of the water, built of rubble and cement, remain, though converted into dwellings and stables. Other smaller cisterns, 93 feet in length, 20 in width, and 27 in height, to the vault, are met with. Temples were erected over the fountains which supplied this aqueduct; the conduit for water was 6 feet in height, and 4 in width, gathered in at the top like a pyramid, and lined internally with a beautiful cement, in high preservation. This aqueduct passed by a tunnel through the hill, and at every 180 feet perpendicular shafts, 4 feet in diameter, were formed of courses of squared stone, which were carried up 4 feet above the surface of the ground; these shafts were used for drawing up the soil, and afterwards left for ventilation.

Near Udena is another aqueduct, built by the Carthaginians; a thousand arches of beautiful masonry remain, which are upwards of 100 feet in height; some writers say this was the work of the Romans after they had subjugated the country.

The Aqueduct of Segovia, built by Trajan, of squared stone, laid without mortar, extends upwards of 2220 feet across a valley; in many places it is nearly 100 feet in height.

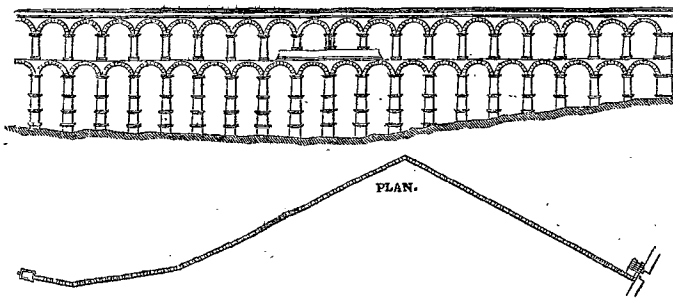


Fig. 215. SEGOVIA.

The Aqueduct at Constantinople was erected by Hadrian before the foundation of the new city by Constantine; afterwards it bore the name of Valens, as well as that of Theodosius. It consists of two tiers of arches, built with alternate layers of stone and brick, in a similar manner to the walls of the city.

The Aqueduct at Lisbon, where it crosses the valley of the Aliantara, about a mile from the city, consists of thirty-five arches, one of which, measured to the soffite, is 231 feet, and the entire height of the structure at this place is said to be 263 feet. The span of the principal arch is 108 feet, and the thickness 23 feet 8 inches. A vaulted corridor, 9½ feet high, and 5 feet in breadth, passes over three arches, on each side of which corridor is a semicircular channel for the water to flow, 13 inches in diameter.

Aqueducts were built throughout the eastern as well as western provinces, and Pliny, in one of his letters to the emperor, says, that the inhabitants of the city of Nicomedia had expended 3,000,229 sesterces (about 24,000*l.*) in building an aqueduct, which did not answer the purpose, and, consequently, was abandoned to ruin. A second attempt in another situation was made, at an expense of more than 2,000,000 of sesterces, which also failed. Pliny himself then examined some springs from whence the water might be conveyed over arches, as was attempted in the first design, and in such a manner, that the whole city might be supplied; he recommends the use of brick for turning the new arches, as it was cheaper and easier to carry up a work in that material; he also requested the emperor to send some engineer skilled in the management of waterworks to undertake the construction. Trajan, in his reply, observes, that every province is provided with men of skill and ingenuity, and that Greece supplied most of the architects that came to Rome.

Canals in Italy and the Roman Empire.—Canals in the early history of Italy seem to have been formed, either for the transport of an army, or for draining a morass or marsh: that cut through the Pontine marshes, 162 years before Christ, was for the purpose of rendering the country more salubrious. Before this period the Etruscans had cut many canals, and they executed the Fossa Phillistina and the Fossa Carbonania, which drew their waters from the Po; indeed the country watered by this river has always been the scene where the great undertakings in Italy connected with inland navigation have been carried out.

The consul Caius Marius, about 51 years before Christ, was sent into Provence at the head of an army, to defend it against the incursions of the northern barbarians, and established himself in the neighbourhood of Arles, on a spot where he could with facility receive his supplies by means of the Rhone from the sea. The river was difficult of entry, in consequence of the shoals thrown up at the mouth, and this consul undertook to dig a canal, and conduct the waters of the Rhone from the left bank, opposite his camp, into a haven called Fos, where the vessels lay. This canal, called the Fossa Mariana, supplied him with all that was required, and may be traced to Marseilles, where the inhabitants benefited considerably from it.

The difference of level between two seas was not so readily overcome by the Greeks, when they attempted to cut through the Isthmus of Corinth, in the time of Demetrius Poliorcetes, at which period it was the practice to transport light vessels across the isthmus, a distance of five miles, on machines constructed for the purpose, which was continued in the wars of the Turks and Venetians. Julius Cæsar, Caligula, and Nero, renewed the attempt to unite the Ionian Sea with the Archipelago, but were frustrated, by finding that the water in the Corinthian Gulf was much higher than at Cenchreæ, and, consequently, the Island Egina would have been flooded, and the canal rendered unserviceable.

It was the important part of the business of the Roman proconsuls in the distant parts of the empire to lay before the emperors the best method of changing the courses of rivers, for the purpose of more readily communicating from the sea to the centre of the provinces; of this we have many examples. Lucius Verus, general of the Roman army in Gaul, undertook to unite the Saone and the Moselle by a canal, and to open a communication to the Mediterranean and German Ocean, by means of the Rhone, the Saone, the Moselle, and the Rhine; his death prevented the execution of this project.

The object of these works was to facilitate, in the first instance, the expediting the proconsular legions, which every year were sent from Rome to the remote provinces. The great Fossa Drusiana, supplied by the Rhine, was executed by Drusus Germanicus, to increase the river Yssel, by which he transported his army into the north.

Corbulon afterwards, either to establish a more convenient passage for his troops into the British Isles, or to drain the stagnant waters of the Rhine, which overflowed extensive tracts, made so large a cut in that river at Batavodurum, that he diverted almost all the water from it, and led it into his canal, which acquired the name of Fossa Corbulonis, now called the Leek, the waters of which, under the name of the Meuse, run into the Northern Sea.

Emilius Scaurus united the waters of the Po, near Placentia, to drain the marshes, and there is no river in Italy that was not made by the Romans useful for the passage of troops or provisions. The river Marrechia, near Rimini, was ennobled by Augustus Cæsar

with a magnificent bridge, that still remains entire, and has defied all the ravages of time; it is an early instance of a skewed bridge, and was afterwards adapted to form the port of a canal or basin, for the convenience of the boats provided for the consular army, which marched by the Emilian way to the provinces.

Pliny's correspondence with the emperor Trajan proves the importance attached to this subject; the consul in a letter (50.) points out such designs as were worthy the glorious and immortal name of Trajan, "they being no less useful than magnificent." He describes an extensive lake near the city of Nicomedia, upon which the commodities of the country were easily and cheaply transported to the high road, from thence were conveyed on carriages to the sea-side at great charge and labour; to remedy this inconvenience, he recommends that a canal should be, if possible, cut from the lake to the sea, observing that one had already been attempted by one of the kings of the country, but whether for the purpose of draining the adjacent lands, or making a communication between the lake and the river, was uncertain: these useful works, in common with all others, fell to decay with the decline of the Roman empire: during the disastrous period which succeeded, until the time of Charlemagne, Europe is deficient in any examples of similar undertakings: this sovereign commenced the projects of uniting the Rhine to the Danube, and of opening a new communication between the German Ocean and the Black Sea.

The Italian republics, in the twelfth century, revived the arts and sciences, and the first signs of returning activity was to open the navigation by sea and by rivers long neglected. The Venetians, driven by Attila from the neighbouring lands of Italy, assembled themselves in the marshes of the Gulf of the Adriatic, which, in process of time, gave rise to a new maritime city, preserving a semblance in its laws to the ancient Roman republic; they soon converted the marshes into ports of great security, and the waters were covered with numerous fleets, which enabled them to carry on a commerce with the east, by which they became the merchants of all Europe.

Between the twelfth and fifteenth centuries, various improvements were effected in the navigation of the Brenta, from Padua to Venice; the Mincio from Mantua to the Po; the Arno from Pisa to the sea; the Reno from Bologna to Primaro; the Tesino and Adda to Milan: and on this latter occasion, the Italian architects adopted the use of movable gates to sustain the falls of the river, and afford a passage to boats, whether the level rose or fell; for this discovery in the improvement of internal navigation we are indebted to Italy.

Mantua, after the death of the Countess Matilda, became a republic, and one of its first efforts was to improve the navigation of the Mincio, so celebrated by the poets.

Its waters then overran the country, and becoming stagnant, rendered all the air around it unwholesome; in its course towards the Po, it formed three arms, and discharged itself with so much rapidity, that it was useless for navigation. In 1188, Alberto Pitentino erected that famous structure of stone, resembling a bridge and portico, which unites the gate of Cepetto with the neighbourhood of the ports, the object of which was to form the upper lake by the drainage of the marshes; he converted the Mincio into a canal, and restored it to its ancient course, uniting it with the Po, from whence it had been diverted in the time of the Romans by Quintus Curtius Hostilius; this great work consumed ten years in the execution, and the rise and fall was regulated at Governolo, in such a manner that boats could ascend to Mantua and descend to Po, and the depth of its waters was so equally maintained, that it was navigable for a distance of twelve miles: it is from this period we must date the application of locks.

The Lake Maggiore is the source of the Tesino, which in its course is divided into several streams, but which are again united before it enters the Po, near Pavia. For the whole distance it is navigable, although at Pan Perduto, where the fall is considerable, it is sometimes hazardous. Immediately below this spot commences the canal to Milan, which at Abbiate divides into two channels. The entire length of the excavation is about 32 Italian miles, and its breadth 70 Milanese cubits.

The Canal della Martesana, by some supposed to have been executed by Leonardi da Vinci, was made in the year 1460, under the Duke Francis Sforza; Leonardi da Vinci joined the two canals some time during the reign of Francis I. The Canal della Martesana, which is drawn from the Adda, is in length 24 miles, and width about 18 cubits; but when constructed at first, the water it contained was barely sufficient for navigation for more than two days in the week, and this, when all the openings for the purposes of irrigation were closed.

One of the branches of this canal was carried for several miles by a stone dyke, and afterwards passed through a deep cutting; the other branch had its course through the rock, after which it was supported on one side by a lofty embankment, where it crossed the Molgara river by an aqueduct of three stone arches.

Before the introduction of locks, contrivances called conches were in use to moderate the too great declivity of the rivers, and which were opened to allow vessels to pass through: these openings were 16 or 18 feet in width; a balance lever, loaded at the end, was made to turn on a pivot, and with it three hanging posts, united by an iron bar,

which crossed them immediately above the sill; besides these three perpendicular hanging posts were two others, let some inches into the side walls. These five posts were all on the same face, and the spaces between them were all equal. When the balance beam turned upon its pivot, the three middle posts alone opened, and allowed the boats to pass, after which the balance beam was turned back to its former position. At a little distance was placed another balance beam, having attached to it a wide plank, to allow the lock keeper to pass over, as well as to place in the grooves of the hanging posts the small planks which served to exclude the water, by closing up the intervals; these were on the side opposed to the current, and in number sufficient to keep the water at the required level. Such gates, or contrivances for damming up the waters of a river, were in use at a very early time in Italy, and two such were constructed at Governolo, in the twelfth century, to pen up the waters of the Mincio on the side of Mantua.

Zendrini, in his twelfth chapter, *Delle Acque Correnti*, has informed us of the change made on this system in the year 1481, by the two brothers Dionisio and Pietro Domenico, of Viterbo; they were the first who used a lock chamber, inclosed by a double pair of gates. So important an invention was made known and introduced throughout Europe, and Leonardi da Vinci united the two canals of Milan by means of six such locks, having a fall of seventeen braces; this was completed in the year 1497, as an inscription placed over the last sluice stated.

CATARACTAM IN ELIVO EXTRUCTUM UT PER INÆQUALE SOLUM AD URBES COMMODITATEM ULTRO UTROQUE NAVES COMMEARENT. ANNO 1497.

All the other canals in Italy soon adopted them, and the whole system of inland navigation was greatly altered as well as benefited.

Zendrini's account of the lock formed by the two brothers, Dionisio and Pietro Domenico, clock-makers of Viterbo, is as follows:—"In the year 1481, they obtained from the Signiori Contarini a certain site in the Bastia di Stra, a place well known near Padua, to form in it a *soratore* of the Piovego, which was a canal from Padua to Stra; and in a petition made by these two brothers, of the same year, it is expressed that they will so act, that the boats will pass from the inclosure at Stra without any danger, managing it in such a way that the water shall flow out with ease, and the boats shall neither be unloaded nor required to be drawn; the conditions added are, that they shall form the ingegno, or execute the work, and also maintain it; this being granted with the revenue they demand, in which is expressly comprised the lock of Stra. The aforesaid brothers being required to form a *buova*, for the further perfection of the work."

The State of Venice, according to Zendrini, has the honour of being the first to adopt this invention; and this is all the information that can be obtained.

In the Milanese territory are several other canals, many for irrigation; near to Ollegio is a canal, which is fifteen miles in length, used for the purposes of navigation: it passes Buffolaro, Biagrasso, and Arsago to Milan. At Abiato is a branch eleven miles in length; its breadth at top is 130 feet, and at bottom forty-six; this canal was made in the thirteenth century.

The great canal of Tesino and the branch from Pavia unite at Milan: the Muzza, which commences at Cassano, is in length forty miles, and has its other termination at Castiglione.

In Piedmont are many considerable canals. The Naviglio d' Inea is in length thirty-eight miles; this unites the Doria Baltea with the Sessia: whilst another branch, thirteen miles in length, unites the Gardena river.

A canal passes from Dora Baltea, 27 miles in length, to the Po, which it joins four miles below Casal.

The Naviglio novo also falls into the Po, ten miles above Turin.

Along the Po, below the Milanese, the canal called Albinia falls into that river, ten miles above Pavia. At Cremona the Naviglio della Communila unites the Lerico and the Oglio, whilst other branches connect with the Po.

The Fossa di Puzzola is fifteen miles in length, unites the Mincio with the Tartaro: the canal of St. George, 6 miles in length, connects the Lake of Mantua with the canal of Puzzola; and that of Martenaro, 8 miles in length, which passes to Borgo Fute, under the same lake with the Po. The Fossa Maestra is 5 miles in length, and joins Ozoma to the canal of Montanara. The Fossero, 7 miles in length, commences at the Mincio.

From Secchio to Panaro, by Modena, is a canal 16 miles in length, with several branches for the purposes of navigation and irrigation.

Fossa Rangone in the papal states is cut parallel to the Panaro, and two branches are made from it, one to Po mort. From Mansolino is a canal 22 miles in length; a portion of it is called Condotto di Conti. The Canal from Bologna to Ferrara is called di Naviglio, and terminates in the extensive marshes after a length of 24 miles. At Primaro, the Canal di Medicina falls into the Po. From the Great Po to the Po mort is the Canal

di Bianio, the Naviglio Ferranese. The Gulf of Venice is connected with the Po by a canal, 6 miles in length, called Val d' Albama.

Besides these are a vast number of branches, which are solely used for the purposes of irrigation.

Ferrara is connected with Venice by the Po and several canals; the canal Ponfilio conducts to Pont di Lago Oscuro; here the Po is entered, and its navigation continues for forty miles; when passing four miles along the canal of Cavenella, the village of Laurio is arrived at. At nine miles upon the Adige are the sluices of Brondo, which are only 28 miles from Venice; soon after the Venetian lagunes are entered. The Bachiglione was formerly the chief navigation at Padua; at Vicenza it unites with the Rherone, and then it becomes navigable for vessels of considerable burthen. After passing Padua for fifty miles, its course is winding, and it then enters the Levant at Bundolo. Between Padua and Vicenza are several sluices. These sluice gates, or pertuis, as they have been designated, were thus contrived.

The lower beam of each gate was framed with the head and heel posts, so as to allow a space of 6 inches between it and the sill. From the middle beam to the top, the gates were planked over in the ordinary way; the lower part was left open, or in skeleton framing, and was closed by paddles or sluices, which were moved up and down by a rack and pinion. When the paddles were let down, they descended three or four inches lower than the surface of the floor on the lower side, which acted as a rebate, against which they pressed, and effectually shut the lock. They also had a bearing against the lower cross-beam of the gate, and the head and heel posts rested on square stones, made fast in the sill.

To make use of gates upon this construction, it was necessary first to raise the paddle as high as the lower cross-beam, which permitted the water to pass through at the foot of the gate. The paddles were then elevated to the height of the middle beam, which was placed at the ordinary level of the water, usually 4 or 5 feet deep upon the sill.

These gates were easily opened, as the boarded part was entirely out of the water, and a deposit on the floor of the chamber of the lock could form but little obstruction, as from the scour of the water, the greater part would be washed away. The only serious objection to this early contrivance in aid of internal navigation is the injury that vessels might sustain at the time they were passing through, when one half of their length would be out of the water, producing a considerable strain upon them. The water passing through a space, walled in on both sides, would, to a certain extent, allow the barge or vessel to slide down an apparent plane; but, before it could again resume its level position, it would be subjected to another strain. These side walls were, however, made of considerable length, a foot being usually allowed for every inch of fall; a timber floor was laid throughout, to prevent the force of the water from deepening and undermining the foundations.

Bassanallo had a canal 11 miles in length, at the commencement of the thirteenth century; in its passage it passed two aqueducts, and the vessels loaded with stone to Venice chiefly navigated it.

The Brenta is navigable fifteen miles above Padua, and it unites with the Bachiglione a few miles beyond that city. There is also a communication with the Adige by a canal six miles in length. Another cut, 20 miles in length, passes from Padua to Venice; its fall of 50 feet is divided into four locks.

In the lagunes are several canals; one which skirts them, called the Novella Brenta, is 36 miles in length.

At Leghorn is a fine canal 15 miles in length, 45 feet in breadth, and 4 feet in depth, which receives its supply from the Arno. Men usually haul the vessels, the fall being scarcely perceptible.

Drainage. — The Pontine marshes derive their name from an ancient town called Pometia, whose exact site is not known, and which had totally disappeared before the time of Pliny. They comprise that part of the Campania or ancient Latium situated on the south-east of Rome, and on the confines of Naples. Their length is about 42,000 metres, extending from Cisterna to Terracina; their width is not so much: their longitudinal axis is from south-east to north-west, the direction of the celebrated Appian Way, which, in crossing their marshes, is almost parallel to the shores of the Tyrrhenian Sea.

At the south-eastern extremity is the ancient Auxur or Terracina, the distance of which place from the house now called Bonificazione, to the port S. Sebastian, or Porta Capenna at Rome, where the Appian Way formerly issued, is 91,841 metres, about 62½ ancient miles, each of which is equal to 1471·2 metres.

The distance from the above points to the Porta S. Giovanni, which is the route now followed, is 101,120 metres: this modern route pursues the Appian Way for 45,000 metres, which is comprised between Terracina and Cisterna. The shortest distance between the house of Bonificazione and the gates of S. Sebastian and S. Giovanni, are 90,421 metres, and to the latter 91,025 metres.

Starting from Terracina, and following the edge of the marsh, we find it separated from the sea by a narrow down: a similar tract of land, much more considerable, and an

alluvial deposit, interposes between the sea and the marshes on their western side, in a direction parallel to their longitudinal axis. Their eastern side is bounded by a lofty chain of calcareous mountains, called Monte Lepino, which extend from Terracina to Cori, Rocca massimi, Monte Ferlino, &c. &c. Their southern limit touches the neck, which joins the northern extremity of the chain just mentioned to a group of mountains, among which Artemisia is distinguished, and which has Velletri on the opposite side; Gensanno, Albano, Castel Gondolfo, &c. on the western side: the height of this neck is the common summit of the two inclined planes; one descends into the Pontine marshes, the other into the valley of Sacco, separated by the Lepino mountains from the former, to which it is superior; this is called the basin of the Lake Celano, formerly the Lake Fucinus and that of the Anieno.

The neck of land at Velletri is covered with a volcanic bed, occupying a considerable extent on the south-east and north-west of Rome; this has been thrown from several craters which are now formed into lakes; of these there are at least ten in number: thus the Pontine marshes are bounded on the north by a volcanic soil, on the east by a calcareous chain, and on the south and west by an alluvial deposit.

At the point of the angle formed on the sea-shore by the two latter directions is a remarkable calcareous pointed hill, detached from the great calcareous chain by the downs and marshes, to which are attached by a solid and resisting mass two other downs, the southern and western extremity of which protects the marsh against the action of the waves. This hill is Circe, or the Monte Circeo, and rises 525 metres above the sea; it is entirely isolated at the extremity of the vast plain, which it commands, and was probably an island originally; it now serves as a contrefort to the alluvium of the Pontine marshes, which were formerly an archipelago of small islands opposite the Gulf of Gaeta and the road of Terracina. The nucleus of Circe is a primitive rock, whose subterranean union with the calcareous masses of the Apennines, is now marked by thick beds of alluvium of volcanic products. The western down, which separates the sea from Machia di Cesterna and the Machia Terracina, appear to have been first formed, bounded on the north by the Cape of Astura, and on the south by Monte Circeo; the southern down is much narrower, and altogether of a later formation. These marshes were probably for a length of time a gulf, or species of lagune, afterwards covered by alluvium, brought down by the various rivers that traverse it.

Soundings were made in 1811 near the sources of the Uffente, at the foot of the mountains Sezze and Piperno, at 16,000 metres distance from the present sea-shore, and carried to 22 metres of depth under the waters of the river, or 17 metres below the actual bed, when marine sand, shells, debris of marine plants, in good preservation, were brought up; this proves that the sea must have once bathed the feet of the mountains which now bound the eastern side of the marsh, and that its bed had a rapid fall from this ancient shore. The Pontine marshes may then have afforded to vessels an asylum or harbour, where the largest might have anchored; one of the principal entrances to which was probably at a little distance from Terracina, where is the present mouth of the Badino.

The soundings made at the foot of the mountains arrived at the marine sand at 17 metres; other soundings, made near Circe, brought up sands and marine shells at a much less depth; thus proving that the ancient bed of the sea gradually inclined from Circe to the shore, at the foot of the mountains, where it again suddenly rose; other observations show that in the Pontine marshes formerly high beds and islands existed, which greatly favoured the formation of the downs; for over a large portion of them, a stratum of very hard matter is found, the breaking up of which is attended with considerable difficulty; this stratum is under the peat, and might have been formed from a deposit of the waters, which flow from the foot of the mountains, one of the sources of which is called Aqua Puzza, or stinking water; these waters spread themselves in various directions, and deposit the earthy matter they hold in solution, thus forming beds of hard stone.

The filling up of the Pontine marshes has been the result of the several rivers and torrents, which, descending from the mountains, have carried in their course a large quantity of deposit; the alluvium is of considerable thickness over the greater portion, and is covered with a thick mud, produced from the decomposition of plants, which apparently has been going on for ages.

The whole of the land to the north-west, beyond the Cape of Astura, is classic ground; at every step we find places described and celebrated by the Roman poets. The adventures of Ulysses and his companions on the Isle of Circe, those of the warrior Camillus and his father, Metabus, who reigned at Piperno, are to be found in Virgil. The scenes of the last book of the Æneid were laid in the country situated to the east of Cisterna, Albano, and Velitri, towards the sea-coast, where Ardea still remains, the ancient capital of the Rutuli, where Turnus was king, and towards Lavinium, now Pratica, Laurentum, &c. &c.

The waters of the fountain Ferronia, which Horace mentions, still run near Terracina, at the place where stood the temple of the goddess.

The first inhabitants of this district, the Volsci, were a warlike and powerful people governed by a king, but afterwards divided into several republics. This latter kind of

government produced many private and independent interests, which eventually caused this people to be subdued by the Romans. There is not a vestige or tradition of any hydraulic works executed by them, though there are considerable remains both of their sculpture and architecture.

The first work recorded is the Appian Way, undertaken in the four hundred and forty-second year from the foundation of Rome, and finished in five years by Appius Claudius, called Cœcus; during his censorship, which was prolonged beyond the legal term, he also constructed the first aqueduct.

To form this road, it must have been necessary to drain the marshes to some extent, but of this we are not informed. A hundred and forty years afterwards, the Consul Cornelius Cethegus undertook to do this more effectually; but various causes interrupted the progress of these works until the time of the perpetual dictatorship of Julius Cæsar, who intended to have performed vast projects, which were prevented by his death. Augustus, who undertook to turn the course of the Tiber from Ostia, commenced his works on a more extended plan, and it is supposed that during his reign, the canal on each side of the Appian Way was formed, which served for the purposes of navigation as well as drainage. This emperor also cut another large canal along the western side, between the Lakes Monaci, Caprolace, and Paola, passing the foot of Monte Circeo, and afterwards continued it towards Terracina. Besides this canal, parallel to the shore, there are on the other side two excavations, evidently made for drainage only, one of which is the Gorgo Leccino, intended to conduct the water from the upper part of the marsh out of their basin towards Fosse Verde; the other is the Rio Martino, whose line of direction is more in the centre of the marshes; this was the greatest work ever undertaken, but history does not mention when it was executed, or who was its engineer. Nerva and Trajan improved the Appian Way, constructed many bridges, and several inscriptions show the interest the latter emperor took in forming the road, but it does not appear that the drainage occupied any portion of his attention. There is very little mention of these marshes until the time of Theodoric, who confided their drainage to the Patrician Decius, and several inscriptions found at Terracina mention works he performed at the end of the sixth and commencement of the following century.

From the thirteenth to the middle of the eighteenth century, the draining of the Pontine marshes was a subject that occupied the attention of the successively appointed popes.

Leo X. and Sixtus V. expended vast sums, and the first gave to Julius de Medici, not only authority, but money to pursue the work; it is to him that we may attribute the cutting of the canal, Portatorre di Badino, the works being conducted under an engineer of the name of Jean Scotti: Fiume Sisto was a canal executed under the latter pope, the course of which nearly follows that of the ancient Fiume Antiquo; this excavation was performed about the year 1588, under the direction of the civil engineer, Ascanio Fenizi.

In the year 1759, Clement XIII. turned his attention to this important matter, and ordered a detailed account to be drawn up of the state of the Pontine marshes, and an estimate to be made of the expense that would be necessary to complete one portion of the work; but a famine happening in the year 1665, when the inhabitants of the papal states were much reduced, the funds collected were exhausted for food, and consequently nothing was done in the way of draining. Clement XIV. Ganganelli, who was his successor, did nothing; and it was not until Pius VII., in the year 1775, was elected pope, that the works were recommenced; he altered, during his sovereignty, the character of these marshes, and performed several very important excavations for the purpose of completing the drainage.

These marshes contain an area of 1,106,370,000 square metres, though by some it is estimated at 1,302,610,700 square metres; and it is calculated that the average quantity of rain that falls into this vast basin amounts to 930,064,042 cubic inches. The volume of water that is discharged, however, is more than double that quantity, being estimated at 2,352,573,939 cubic metres.

In the calculation from whence the above is taken, the greatest discrepancy seems to arise in the allowance made for evaporation and infiltration; the water which pours into them, and so adds to the quantity beyond that produced by the rains, is brought down by the rivers Ninfa, Cavata, Fiume coperta Cavatella, and Uffente.

The canal Pio, which discharges a considerable quantity, has a very regular fall throughout; for its first length it is only ·00072 metres in a metre, and afterwards ·000068 metres in a metre for the remainder of its course. The fall of these waters in a length of 3728 metres being 0·734 metres high water, and ·525 when at its lowest.

Various methods are adopted to keep open these canals, and for several centuries it was the practice to drive herds of buffaloes through them, which either trod down, or destroyed the aquatic plants which are here produced in abundance. A cylinder about 18 inches in diameter, and 10 feet in length, was afterwards used; this roller, armed with scythes, by means of a chain was moved along by a punt or boat; twelve buffaloes were attached to drag it when required for use; another method was to mow down the weeds and plants

by a scythe of a novel form, of iron, about ten feet in length, with a cord attached at each end. A man walking on each bank, by means of ropes, drew this concave cutting knife along the bottom, when the plants bending in a contrary direction to the movement of the scythe, became easily separated; it was found that when the roots were left, the plants, after cutting, shot up much stronger.

The Cloaca Maxima, or great sewer of Rome, is constructed with large blocks of Albano stone, called Pepperino; it carried off the waters from the Forum, and drained the public

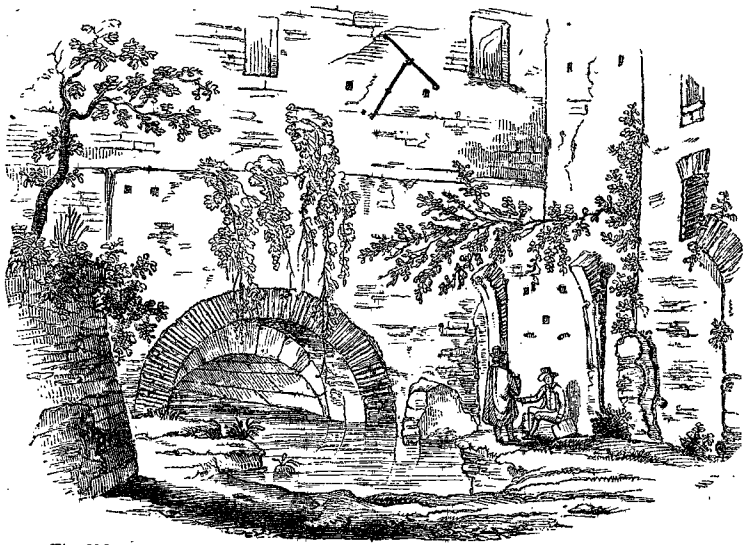


Fig. 216. CLOACA MAXIMA.

buildings into the Tiber. It is about 14 feet in width, and 32 feet in height; the arch which covers it is semicircular, and formed of three rings of voussoirs. Where it enters the Tiber, the banks are protected by walls of a similar construction; at present, from the elevation of the bed of the river, the upper part only, which is arched over, can be seen; this great work is said to have been executed in the time of the kings; its solidity is remarkable, and its arch is sufficiently strong to bear any weights that could pass over it. When the habitations of the Romans were mere huts, it seems extraordinary that so costly a construction for the purposes of drainage should have been executed, but it shows that in the early history of their city, all that was undertaken for public utility was carried out with a spirit and magnificence surpassing any thing done by other nations who have advanced more in civilisation and refinement.

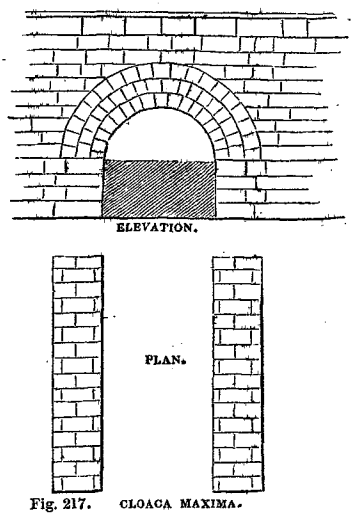


Fig. 217. CLOACA MAXIMA.

One of the chief causes of the unhealthiness of Rome at the present day is the imperfect state of its drainage. This vast sewer, buried by the filling up of the river, no longer serves to convey the accumulations of filth, or the waters from the low valleys between the hills, where it is now suffered to pass off either by evaporation or filtration. When the Coliseum was examined some years ago, and the earth taken out between the walls that supported the arena, a quantity of water drained into the excavations, and remained there, the Cloaca Maxima no longer carrying it off, as it formerly did in the most effectual

manner; consequently, fearing the pestilential effects of such a vast pool, the earth was again thrown in, and all the substructions of this interesting building hidden from sight.

This sewer is not of larger dimensions than another discovered in 1742, which passed under the Comitium and Forum, 40 palms below the present surface; every part of the imperial city had its sewers, and many are formed of pepperino stone, so universally used before the introduction of the travertine, which did not take place till long after. The Bocca della Verita is a large marble covering to one of the sewers of the Forum, which admitted the surface water into it. When we recollect that the quantity of water conveyed by the aqueducts into the imperial city surpassed that which any modern town receives, we naturally enquire by what means the baths and fountains were cleansed, or the surplus quantity carried off; and on examining the various buildings, we find admirable and ample provision for their draining, and what is of far more importance, a dimension given to the sewers sufficient to render them effective; their sectional area was increased as they advanced, and there appears to have been in Rome one general direction, which proportioned the parts as well as the whole. Had Rome been divided into districts, each with its board of directors, sewers might have been built, as in London, like an inverted telescope, growing less as they advanced, instead of greater, or two sewers might have been conducted into one, whose sectional area was not equal to either.

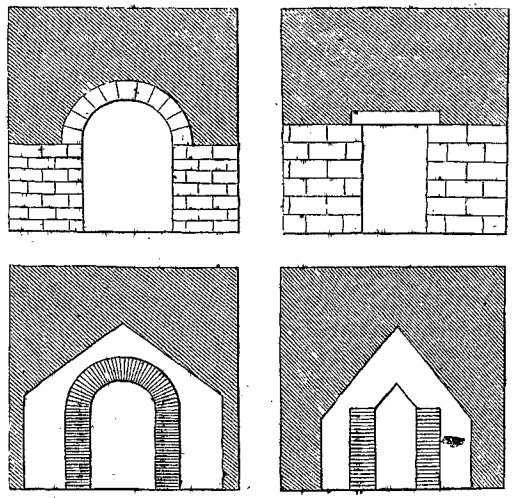


Fig. 218. SECTIONS OF ROMAN SEWERS.

Fig. 219. BOCCA DELLA VERITA.

Alban Lake.—The plan for piercing a tunnel through the wall of the lava, instead of directing the course of the stream, which was running over on the lowest side of the lake into a regular channel, was adopted for two reasons; first, as a preventive against the violent floods that would have taken place whenever the waters received any extraordinary increase; and, secondly, as the space between the level at which the lake overflowed and that of the tunnel, where the banks are six miles round, was of great value, even supposing that the land in those days, as now, was employed to grow wood. The object was not to gain new land, but to recover what the proprietors had been deprived of; indeed, that which was regained may perhaps not even have em-

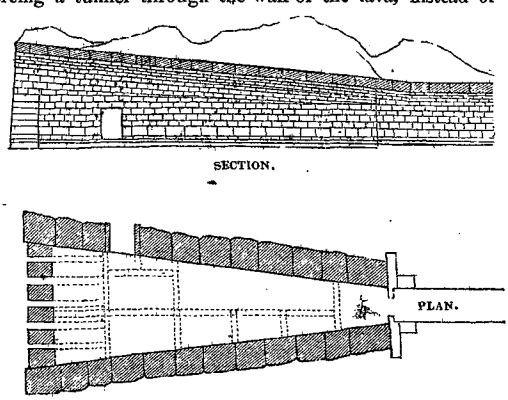
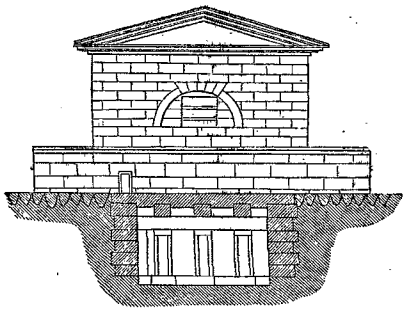


Fig. 220. EMISSARY.

braced the whole of what had been lost in the interior of the crater, by the rise in the surface of the lake.

The nature of the stone cut through to form this tunnel made the execution a task of great difficulty. It is a lava as hard as iron, through which a passage was broken, high enough for a man to walk in it, 3 feet 6 inches broad, and 6000 feet long. On the line of its course, fifty shafts were sunk to the bottom of the projected tunnel, whereby its level and direction were accurately kept and determined. After these shafts were sunk, the workmen commenced cutting away till they met, and the stone was lifted out by means applied at the top of the shafts. When the tunnel was nearly finished, and a thin partition only separated it from the lake, a small hole was made through it, which let off the water by degrees, and enabled the workmen to construct the wall of masonry around the mouth.



ELEVATION.

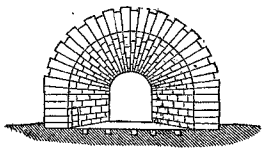


Fig. 221. ARCH OF THE EMISSARIUM.

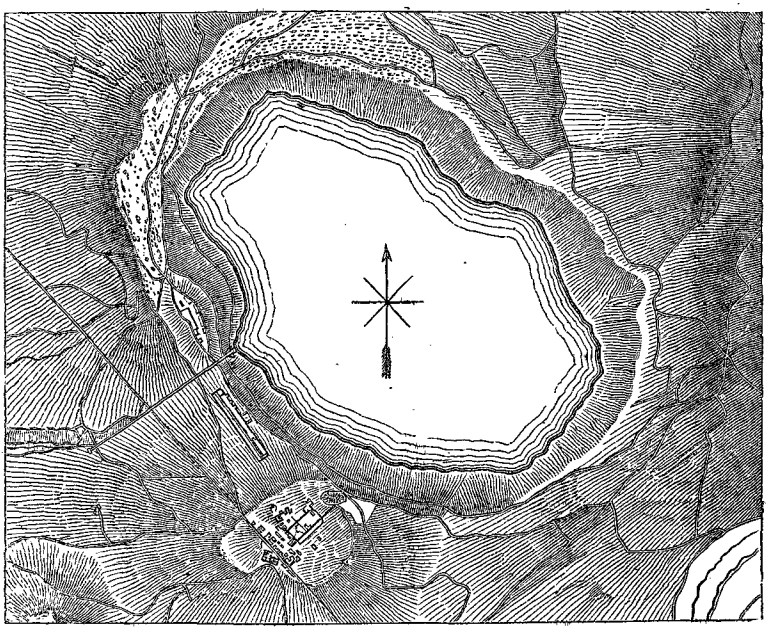


Fig. 222. LAKE ALBANO.

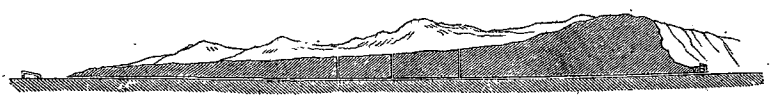


Fig. 223.

The Emissarium is one of the most extraordinary among the works of the Romans; by it was discharged the waters of a lake, which, situated in the bosom of a mountain often rose to a considerable height, and threatened damage to the plains below. It was commenced about 398 years before Christ, at the time the Romans were besieging Veia; the waters had then risen to a height of 310 feet above their ordinary level, and Rome itself was in danger of an inundation. The oracle of Apollo at Delphos was consulted on this occasion, and it replied, that the Romans would take the town of Veia when they should have drained the waters of the lake, by turning their course towards the sea. A prisoner taken by the Roman soldiers, who said he was inspired, made the same answer, and produced the same impression among that credulous people: not doubting the necessity of the work, they undertook it with vigour, and completed it in one year; they tunnelled the mountain on the margin of the lake at the place where is now the Castle Gondolfo, and formed the canal, in which the water usually ran 3 feet in depth: at each extremity is a building or water tower, one at the commencement of the canal opposite the lake, the other where the canal issues into the plain; these were constructed so solidly, and with such nicety of workmanship, that at the present day they serve for the purpose intended, without having needed any repairs. This Roman work astonishes us, from the difficulty of piercing the mountain, composed of rock, in so short a time, the canal being so narrow that two or three workmen only could have been employed at once. This excavation was made by sinking shafts at regular distances, which descended to the line of the canal; by this means the works at several places were carried on at the same time. There must have been still greater difficulty after the emissarium was completed, in opening its communication with the lake, when the water stood at so great a height above it. This work indicates great knowledge in hydraulic architecture as well as in levelling. Of the several shafts sunk one only is uncovered, the remainder are filled up.

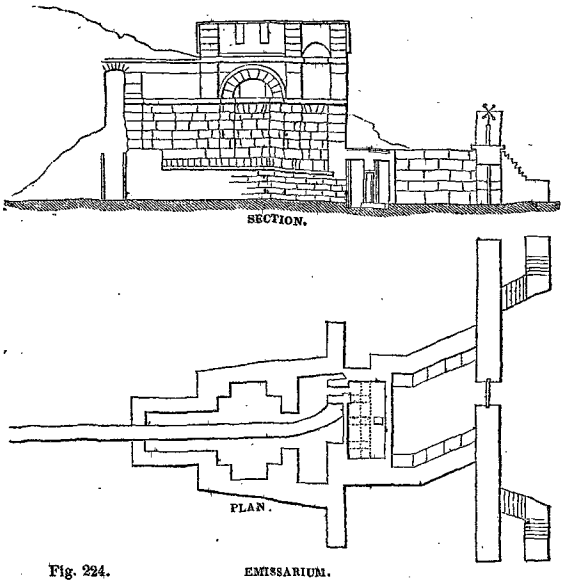


Fig. 224. EMISSARIUM.

When the writer examined this surprising effort of engineering skill in the year 1819, the arched channel was in a very perfect condition; supplied by the guides with pieces of wood on which lighted tapers were mounted, he had the opportunity, by floating them along the gentle current which continued in a straight line, to observe during their progress towards the discharge into the plains below the finely constructed vault. This work was undertaken nearly 400 years before the Christian æra, and we have still the means of studying the arch as constructed at that period, which deserves our highest commendation: an ilex of considerable dimensions had rooted on the blocks of stone which form the side walls encompassing the emissarium, which had displaced some of the upper courses.

A wooden penstock was in use to let off the water from the lake, composed of boards fastened to an outer frame that worked within a groove in the stone at each side, and which seemed to have been the original arrangement made to comply with the words of the oracle, Livy, lib. v. cap. 16. — "Roman, beware lest the Alban water be confined in the lake; beware lest thou suffer it to flow into the sea in a stream; thou shalt form for it a passage over the fields, and by dispersing it in a multitude of channels get rid of it."

It was long the custom of the Romans and the Volscians to celebrate together an annual festival in commemoration of the success of this work; they sacrificed on the occasion a white bull to Jupiter, whom they called *latialis*, and by such ceremonies were maintained a constant inspection and attention to this surprising and early example of tunnelling through the sides of a mountain.

At the Lake Fucinus is a similar work, of greater magnitude: Pliny says it was one of the most memorable of the time, and intended to drain the lake; it was commenced by order of the emperor Claudius: 30,000 men were employed for ten years, and it was

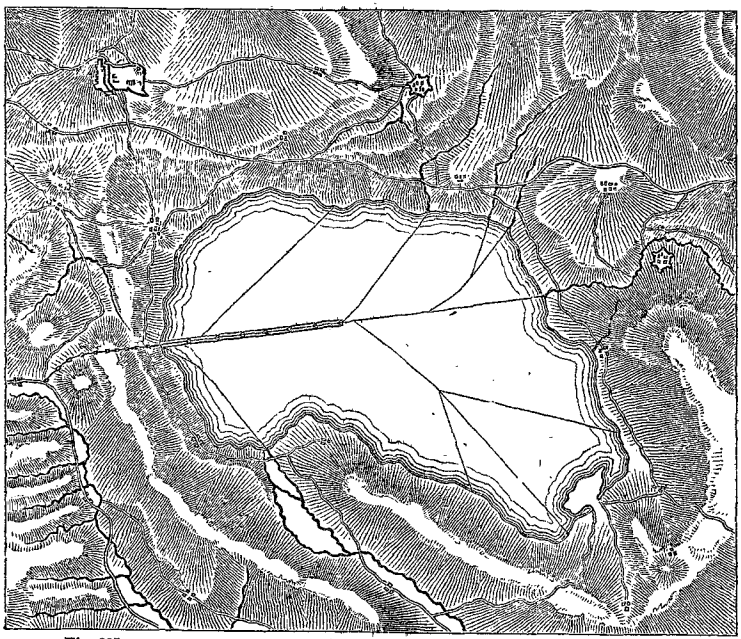


Fig. 225. LAKE FUCINO.

finished, after a vast expense, in the year A. D. 52. Rocks were pierced through, and many hydraulic machines applied to draw off the water, which constantly obstructed the workmen.

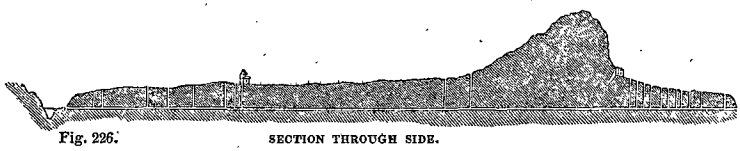


Fig. 226. SECTION THROUGH SIDE.

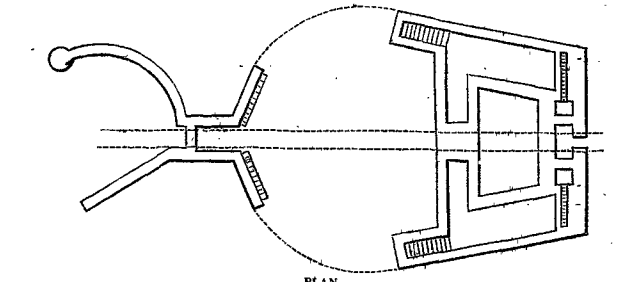
When the canal was perfected through the mountain, a vast assembly of persons was present to witness the passage of the waters from the lake, and previous to their being conducted into the emissarium or great sewer, the emperor gave a vast naval spectacle or combat. Narcissus, his freed-man, superintended, and he allowed the waters to rush with such impetuosity that much mischief was done: we are informed by Tacitus, that the whole was badly conducted, and that the bed of the emissarium or canal was not sufficiently deep to allow the water from the lower part of the lake to drain off; this was attempted to be remedied under the reign of Nero, but the enterprise was abandoned before completed.

The masonry constructed at the mouth of the emissarium is very similar to that already described: two staircases conduct to the platform below, in which are the conduits and sluices to let off the water; the channels are lined with masonry in an admirable manner, and the arch is well executed.

The lake, situated in the country of the Marsi, at the north of the river Liris, is surrounded by a high ridge of mountains called Celano, which are said to be in circuit nearly 50 miles; but the water comprised within their boundary is not more than 10 or 12 feet in depth. Tacitus, *Ann.* lib. xii. cap. 56., gives a very interesting account of this work, and Virgil alludes to the lake (*Æn.* 7. v. 563.) as being well known:

> "Est locus, Italiæ in medio sub montibus altis,
> Nobilis, et famâ multis memoratus in oris,
> Amsancti valles."

The Liris, or, as it is now called, the Garigliano, separates Campania from Latium, and



PLAN.

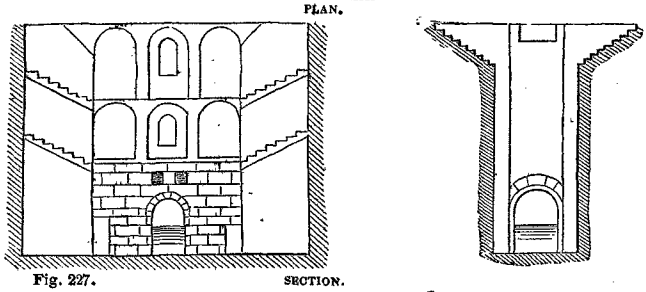


Fig. 227. SECTION.

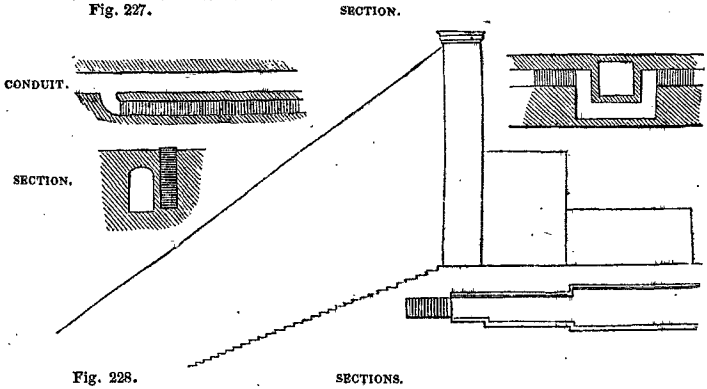


Fig. 228. SECTIONS.

falls into the Mediterranean Sea, south of Mola di Gaieta, where was Cicero's famous Formianum Villa.

The Tombs of the Romans in many instances were in imitation of that which Queen Artemisia raised at Halicarnassus in honour of her husband Mausolus, which ranked among the most celebrated constructed by the ancients. All the towns of Italy had beyond the walls avenues or roads, along which the inhabitants were buried; at Pompeii the Street of the Tombs conducts the traveller to the city gates.

Tumuli were raised over the dead by Greeks, Etruscans, and Romans. In Greece the bodies were first consumed, the ashes put into an urn or earthen vessel, and then deposited in a vault or excavation, made a little below the surface of the ground, sometimes in the recesses of rocks. At Syracuse and Agrigentum many of these are found in the walls which surround them, although the sarcophagi or urns, once within them, containing the burnt remains, have long since disappeared.

In Rome, the practice of burning was not very early introduced; at first the bodies were consigned to their native earth, although among the Etruscans we find mention made of the funeral pile. Sylla, it is said, introduced the custom of burning the body, having fear that his might be ill treated after death. In the Roman sepulchres that have been examined, the skeleton is found with the arms laid close to the sides, a vase with a narrow neck placed upon the breast, another on each side of the head, one on each hand, and one between the legs; a dish once containing eggs, fruit, or birds, and a coin, are also met with. Neither the Greeks nor Romans were allowed burial within their walls, and

Cicero (*De Leg.* lib. ii.), observes, "Hominem mortuum in Urbe ne sepelito neve urito." Plutarch mentions as an exception to this general rule, that all who had gained a triumph might be buried in the Forum, and the ashes of Trajan were deposited within his triumphal column.

Mausoleum of Augustus, though ruined, still exhibits sufficient to indicate its former magnificence: in it was deposited the body of Marcellus, the nephew of Augustus, and those of J. Cæsar, Augustus, and Germanicus. Strabo (lib. v.) informs us, that it was built upon immense foundations of white marble, and covered with evergreens; on the top was a statue of Augustus in bronze; in the vaults below, the ashes were deposited, and around were numerous groves. The same author describes the place where the bodies were burnt: "in the centre of the plain stands the tomb itself, finished in white marble, with iron palisades round, and poplar trees planted within. The inner circular wall still exists with the opus reticulatum, but formerly, as it seems, there were three walls at equal distances, the intervals between which were marked out into certain spaces, so as to produce a greater number of vaults, for the interment of each person separately."

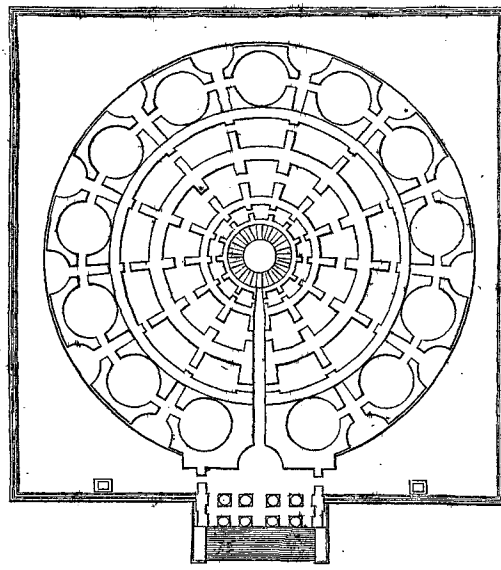


Fig. 229. TOMB OF AUGUSTUS.

This tomb was circular; five concentric walls formed the foundations, which were vaulted to support the upper stories. Thirteen circular vaults composed the outer range, and in the centre a cylindrical stairs conducted to the several chambers and gardens above.

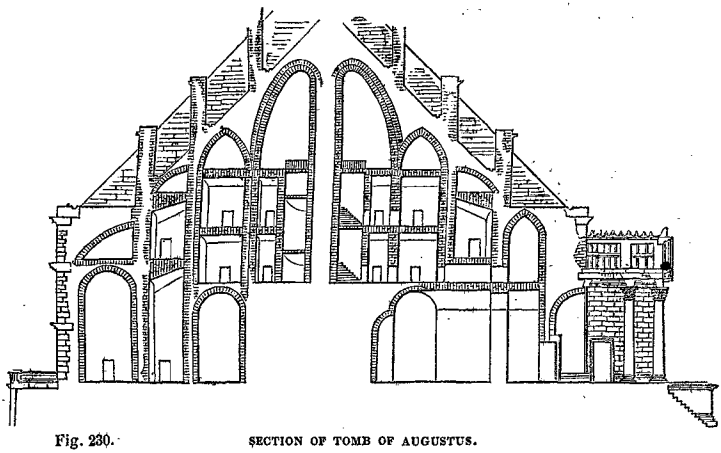


Fig. 230. SECTION OF TOMB OF AUGUSTUS.

The entrance was by a noble portico, and a passage conducted to the several corridors and staircases; on the outside, the walls were carried through the marble casing, and between each circle were planted the evergreens alluded to by Strabo: the statue was elevated 400 feet from the foundations on a pedestal, lifting it above the evergreen forest which covered the conical structure.

Little now remains of this once splendid mausoleum but a circular mass of brickwork, of

enormous thickness; the conical vault has disappeared, and the interior, when the writer was at Rome, was fitted up with seats to form an amphitheatre, where bull-fights were occasionally exhibited. In the views given by Pietro Santi Bartoli, in his work on the sepulchres of Rome, &c. the entrance and outer walls are shown.

The Tomb of the Scipios, discovered in 1780, in a garden to the left of the Appian Way, near the gate of S. Sebastian, is one of the most ancient: it is cut out of tufa, and consists of a series of dark chambers, in one of which is the sarcophagus of L. Scipio Barbatus, the great-grandfather of Scipio Africanus, who was buried, it is supposed, at Liternum, about 565 years after the building of the city, according to Livy.

The Pyramid of Caius Cestius, which stands near the gate of St. Paul, is partly within and partly without the walls; its height is 121 feet, its breadth at the base 96; it is constructed of white marble, probably from the quarries at Luna. It contains a room about 20 feet by 16, and 17 feet high, upon the walls of which are some paintings, representing two females sitting, two standing, with a victory between them; there are also vases and candelabra. Pliny, lib. xxxvi. cap. 13., tells us the tomb of Porsenna was of a pyramidal form, although the Greeks and Romans seldom used this figure.

From an inscription in the Museum Capitolinum, found near the monument of C. Cestius, we learn that five persons were named heirs by his will, and that Pontius Claudius Mela and Pothos erected this pyramid.

Trajan's column was a monument to that emperor, or rather of his victories over the Dacians. Apollodorus is supposed to have been the architect to whom its construction was entrusted, about the year 115 of the Christian era. Dion Cassius states that Trajan himself erected it the year before he set out for Parthia; but from the inscription on it, it would appear to have been raised by the senate and Roman people, when Trajan had for the seventeenth time the tribunitian power, which happened the year the emperor was absent from Rome. Trajan died at Seleucia; his ashes were brought home, and deposited in a golden ball, on the summit of the column, which was contrary to the usual custom of allowing a burial within the walls. The pavement from which this splendid marble column rises is 15 feet below the ordinary level of the streets, the ground having accumulated since its foundation on all sides.

Engineers at the present day are astonished at the simplicity of its construction, and the dimensions of the blocks of marble that compose it. The column is nearly perfect; its pedestal consists only of seven blocks; the cornice is a single piece 20 feet square, and 6 feet 4½ inches thick. The shaft of the column is composed of nineteen courses, each 5 feet in height, and the entire diameter; in the centre a newel is left, around which are cut the stairs that conduct to the summit. The capital, or last of the nineteen blocks of the shaft, is 14 feet square, ornamented with eggs, well sculptured, under which are indications of doric flutings. The shaft is covered with spiral revolutions of sculpture, representing in full relief the various exploits of the emperor.

The height of the pedestal is 17 feet 11 inches; that of the shaft, capital, and base, 97 feet 9 inches, and the ancient part of the pedestal remaining above 9 feet 6 inches, making a total height of 125 feet 1 inch.

The lower diameter of the column is 12 feet 2 inches; the upper 10 feet 9 inches. One hundred and eighty-two steps conduct to the gallery formed above the abacus, on which rises the pedestal that supported the statue of the emperor, as some of his coins show.

Two thousand five hundred figures are sculptured on this beautiful monument, among which the emperor is represented more than fifty times; the figures are 2 feet in height at the bottom of the shaft, and increase as they mount or get farther from view, being at the top nearly 4 feet.

Antoninus Pius also had a similar column dedicated to him by Marcus Aurelius. The height of its present pedestal is 26 feet: the column with its capital and base consists of 19 blocks of white marble. It is in height 97 feet 3 inches, with a pedestal above 6 feet in height: the lower diameter is 13 feet 2 inches; a similar staircase conducts to the summit, and a spiral decoration, like that of Trajan's, winds round the outside; but the subjects are not so well sculptured.

Both these columns are admirably executed, and interesting to the civil as well as military engineer for the attempts made by the sculptor to represent the various bridges, ports, ships, fortifications, implements used to destroy as well as protect; both have been admirably engraved, from casts taken from the columns when scaffolding was erected around them to hoist the present statues of St. Peter and St. Paul, which now terminate them; the author also measured them, and their dimensions are more fully given in the "Antiquities of Rome."

The Mausoleum of Adrian, on the other side of the Tiber, apparently was intended to rival that of Augustus: it had three stories resting on a square basement. Procopius informs us that two stories were decorated with columns and statues, and at the top was the statue of Adrian. "The tomb," he says, "of the emperor stands without the Porta Aurelia, at about a stone's throw from the walls, and is well worth a visit, for it is built of Parian marble; the stones with which the basement is constructed are joined alternately to

each other without cement, and its four sides are all equal. In height it tops the walls of the city; there are also statues on it of men and horses, finished with wonderful skill out of Parian marble. The inhabitants observing some time ago, that it stood like a tower overlooking the city, carried out two arms from the walls to the tomb, and by building them into it united it so that it became a part of the walls." And the same writer tells us that in his time, during the siege, the Goths under Vitiges, having broken the statues, which were of marble and of great size, they threw down large stones made out of their fragments upon the heads of the enemy.

Luitprandus, who wrote in the time of Pope Boniface IV., alludes to this tomb, then a fortress: "in the entrance to the city, there is a castle of great strength and astonishing construction. In front of the gate is a bridge over the Tiber, which is the first in going in or out of Rome: nor is there any other way of passing except over this bridge. But this cannot be done, except by permission of those that hold the castle, which is so high, that a church built at the top in honour of the archangel Michael is called St. Angelo: there is a figure of an angel on the top." The present fortifications were made about 985, by Crescenzio, since whose time it has undergone many changes, though the chamber which contained the porphyry urn, now in the Vatican, and in which were the ashes of the emperor, is still shown.

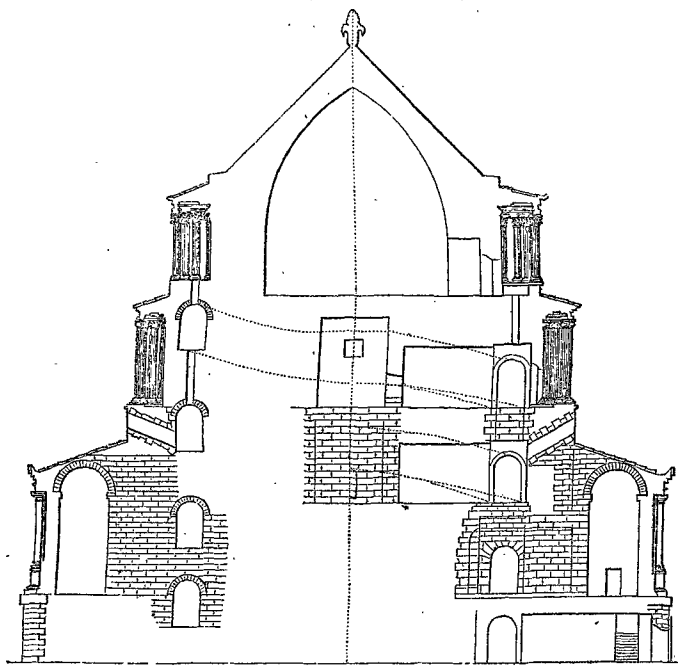


Fig. 231. SECTION OF TOMB OF ADRIAN.

The columns which surrounded this fine tomb formed a part of the church of St. Paul-out-of-the-walls, and in the conflagration, which destroyed that building a few years ago, they perished.

The tombs of the rich citizens were commonly built of marble, and the ground around, enclosed with a wall or iron railing, was planted with trees, as Pausanias, lib. ii. 15. mentions was the practice among the Greeks. Many of these tombs were built during the lifetime of the Romans, as upon some remain such inscriptions as V F, vivus fecit; V F C, vivus faciendum curavit; V S P, vivus *sibi* posuit, and Se vivo fecit; and Pliny severely (Ep. vi. 10.) censures those friends who neglected to complete the tomb after the decease of the individual. Sepulchres common to many families, constructed at vast expense under ground, were called *hypogæa*; such catacombs are found in the neighbourhood of all large cities and towns in Italy. In them were recesses and niches for the urns which contained the ashes of the dead; they were styled *columbaria*, in consequence of bearing a resemblance to the arrangement of a dovecote.

The Remains of the Tomb of Alexander Severus show two chambers which contained sarcophagi, and the passages which led to them.

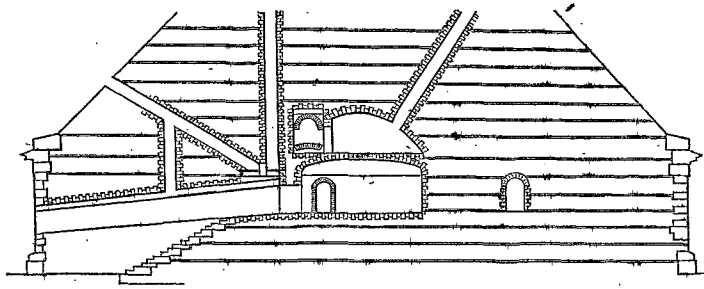


Fig. 232.

Machines and Engines used by the Romans are by Vitruvius divided into three kinds: the scaling machine, constructed for the purpose of ascending without danger, to view works of considerable altitude, formed of timber, put together by the carpenter, and braced strongly in every direction. Ladders of all kinds, particularly those attached to the masts of ships, all came under this first denomination.

Machines for lifting stones and heavy weights, employed for the purposes of construction, were made as follows: —

Three pieces of timber, sufficiently strong for the purpose, were connected together at the top by an iron pin, in such a manner that they could be made to spread extensively at their feet: when these were raised by means of ropes made fast at the top, which assisted in keeping them steady, a block was attached in which were two pulleys, turning on axles, one above the other. Over the upper pulley a leading rope passed, which was let fall, and made to pass under a lower pulley in a bottom block; it was then returned over the bottom pulley of the upper block; the rope again descended to the lower block, to the eye of which it was firmly fastened. The other end of the rope was connected with the axle, which, as it was wound round, elevated the stone or weight to the required height. The axle worked in two gudgeons, sockets for which were made in two pieces or cleets (*chelonia*), affixed to the back of two of the pieces of timber when they were spread out.

Levers, entering mortices, made at each end of the axle, were used to turn it. Iron shears were made fast to the lower block, which opened, and their teeth entered two holes cut in the stone to be raised.

A block containing three pulleys was called trispastos; when the lower system had two pulleys and the upper three, pentaspastos; and when very heavy masses were elevated, longer and stouter beams were required; the pins which united them at top, as well as the axle below, were all made stronger in proportion. When used, guy ropes were attached to the shoulders or top of the three pieces of timber, and if there was no other place convenient to fasten these to, they were fixed to sloping piles driven in the ground, which were well rammed round. A block slung to the head of the machine had a rope carried round it to another block, previously fastened to a pile or stake; passing over its pulley, it returned to the block at the top of the machine, round which the rope passed, and descended to the axle at bottom, to which it was lashed.

By turning the axle with the levers, the machine was used without any danger, the guy ropes attached to the piles keeping it perfectly steady.

When heavier weights still were to be raised, the common axle was not strong enough to be trusted; it was, however, retained, but surrounded with a drum or tympanum; the blocks employed were constructed after a different manner from that already described; at both top and bottom were two ranks of pulleys, the rope passing through a hole in the lower block, so that each end of the rope was equal when extended. It was then bound and made fast to the lower block, and both parts of the ropes so retained, that neither of them could swerve either to the right or left. The ends of the rope were then returned to the outside of the upper block, and passed over its lower pulleys, whence they descended to the lower block, and, passing round its pulleys on the inner side, were carried up right and left, over the tops of the higher pulleys of the upper block; whence descending on the outer sides, they were secured to the axle on the right and left of the drum wheel, about which another rope was now wound, and carried to the capstan. When the capstan was turned, the drum wheel and axle, as well as the ropes fastened to it, being set in motion, the weights were gently raised, and without danger. Sometimes the drum wheel was made sufficiently large to allow men to walk within it, by which means greater power was obtained than with the capstan.

Another machine of an ingenious contrivance, called polyspaston, but which was only used by the most experienced artificers, was a single pole, maintained in its position by four guy ropes placed in opposite directions. Under the place where the guy ropes were attached at top, a couple of checks were fixed, over which was tied the block. Under the block was placed a piece of timber, about 2 feet long, 6 inches by 4. The blocks had three pulleys side by side, and three leading ropes were conducted from this part of the machine down to the lower block, where they passed through its upper pulleys from the side next the pole. They were then carried to the upper block, passing from the outer sides of the lower pulley of the upper block. Again descending to the lower block, they passed round the second rank of pulleys from the inner to the outer sides, and were then returned to the second rank of pulleys in the higher block, over which they passed and returned to the lowest, whence they were again carried upwards, and passing round the uppermost pulley returned to the lower part of the machine.

A third block fixed near the bottom of the pole, called artemo, was made fast at a small distance from the ground; this had three pulleys, round which the ropes passed for the men to work them. By this means, three sets of men working without a capstan could raise a weight to any required height.

A single pole was considered most convenient, as there was dispatch and facility in its use; the situation of the weight, whether before it or to the right or left, was of no consequence. These machines were generally employed for the loading and unloading ships, and the ships themselves were usually drawn on shore by blocks and ropes only.

Ctesiphon's method for removing great weights was well known to the Romans, and Vitruvius tells us that when he was employed to remove the shafts of the columns from the quarry to the site of the temple of Diana at Ephesus, he did not employ the usual means, lest the wheels of the carriages should sink into the soft ground which they had to traverse; he constructed a frame with four pieces of timber, two of which were the length of the shaft of the column, and the other two were placed at the ends, as transverse pieces, to secure them together. Iron pivots inserted into the ends of the shafts, run with lead, worked in gudgeons, were fastened to the transverse pieces, and the pivots having power to turn freely when the oxen were attached to the frame, the columns rolled round, and were conveyed the required distance.

Metagenes, his son, adopted the same method to remove the massive entablatures; he constructed, in addition to the frame, wheels about 12 feet in diameter, and fixed the ends of the blocks of stone into them; the pivots turning in the gudgeons, when the wheels revolved, the blocks remained like axles.

Pæonius attempted to remove from the same quarry a base for the statue of Apollo; this he placed or rather fitted into two wheels, and round their circumference he attached pieces of timber 2 inches square, forming an entire cylinder. A rope was coiled round this, and to the end a yoke of oxen was attached; as the rope uncoiled, the stone by means of the wheels rolled forward; but Pæonius, who had entered into a contract for its removal, had not sufficient funds to complete the work, much additional labour being required to prevent its swerving from a direct line.

Principles of Mechanics. Our knowledge upon this subject is chiefly derived from Vitruvius, but the study of the mechanical sciences commenced with Archimedes in the school of Alexandria, established by Ptolemy Philadelphus, and was extended by Ctesibius and Hero, about 150 years before Christ: these two philosophers first, by an analysis of all the mechanical engines into their primary elements, reduced the actions of which they were capable to the combinations of five simple principles, which they called mechanical powers, and their system was known and practised by the Romans, as it is by us at the present day. Vitruvius explains fully the nature and difference of direct and circular motion, and observes, that rectilinear without circular motion, or circular without rectilinear, are of little use in raising weights. He remarks that the pulleys revolve on axles, which go across the blocks, and are acted upon by straight ropes which coil round the axle of the windlass; when that is put in motion by the levers, it causes the weight to ascend. The pivots of the windlass axle being received into or playing in the gudgeons of the cheeks, and the lever being inserted in the mortice hole prepared for them, are moved in a circular direction, and thus cause the ascent of the weight. Thus an iron lever applied to a weight moves what many hands could not do. When a lever is placed under the weight upon a fulcrum, one man's strength at the end will raise the weight; this is accounted for by the fore part of the lever being under the weight, and at a shorter distance from the fulcrum or centre of motion, whilst the longest part, which is from the centre of motion to the head, being brought into circular motion, the application of a slight power to it will raise great weights.

When the tongue of the lever is placed under the weight, instead of the end being pressed down, it is lifted up; the tongue then, having the ground for a fulcrum, will act on that, as in the first instance it did on the weight, and the tongue will press against the side thereof, as it did on the fulcrum, though by this means the weight will not be so easily

moved. If the tongue of the lever be placed too far under the weight, and the end be too near the centre of pressure, it will have no effect; the distance from the fulcrum to the end of the lever must be greater than from the fulcrum to the tongue.

The steelyard or stateræ is an instance of this principle, and was in common use among the Romans, and our author observes, when the handle of suspension, on which as a centre the beam turns, is placed nearer the end from which the scale hangs, and on the other side of the centre, the weight will be shifted to the different weights of the beam; the farther it is from the centre, the greater will be the load in the scale which it is capable of raising, and that through the equilibrium of the beam; thus a small weight, which, placed near the centre, would have but a feeble effect, in a moment acquires power to raise a very heavy load.

The rudder turns a ship, though ever so deeply laden, from the action of the lever, but Vitruvius also notices that the sails, if only half mast high, will cause the vessel to sail slower than when the yards are hoisted up to the top of the mast, because, not then being near the foot of the mast, which is as it were the centre, but at a distance therefrom, they are acted on by the wind with greater force. For if the fulcrum be placed under the middle of a lever, it is with difficulty that the weight is moved, and that only when the power is applied at the extremity of the lever, so when the sails are no higher than the middle of the mast they have less effect on the motion of the vessel; when, however, raised to the top of the mast, the impulse they receive from an equal wind higher up causes a quicker motion to the ship. Perrault disputes this doctrine in his Commentary, and properly observes that, whether the sails are higher or lower, the motion of the vessel is not affected by it, for the whole moves together, and there is no fixed point to serve as a fulcrum or centre of motion; it is not therefore comparable to a lever, nor can it act as such: it is simply pushed forwards by the wind, and the only advantage in having the sails higher is that the wind is there stronger, while there is a disadvantage from the head of the ship being plunged deeper in the water, which necessarily impedes its course.

Vitruvius continues: "Oars made fast with rope to the thowls (scalmi), when plunged into the water and drawn back by hand, impel the vessel with great force, and cause the prow to cleave the waves, if the blades are at a considerable distance from the centre which is the thowl.

"So also, when loads are carried by four or six men on a pole, the weights are so placed in the middle, that each may bear his portion; for if they passed the centre, one set of men would bear more than the other.

"Oxen also have an equal draft, when the piece which suspends the pole hangs exactly from the middle of the yoke; and when oxen are not equal in strength, by judiciously shifting this suspended piece, one may be made to draw more than the other.

"It is the same in the porter's levers as in the yokes, when the suspending tackle is not in the centre, and one arm of the lever is longer than the other, namely that to which the tackle is shifted; for, in this case, the lever turning upon the points to which the tackle has slid, which now becomes its centre, the longer arm will describe a portion of a larger circle, and the shorter a smaller circle.

"Now, as small wheels revolve with more difficulty than larger ones, so levers and yokes press most on the side which is at the least distance from the fulcrum; and on the contrary, they ease those who bear that arm which is at the greatest distance from the fulcrum.

"All these machines regulate either rectilinear or circular motion, by means of the centre or fulcrum, as also waggons, chariots, drum-wheels, wheels of carriages, screws, scorpions, balistæ, presses, and other instruments, which produce their effects by means of rectilinear and circular motions."

Engines for raising Water. Tympanum. — The Romans were acquainted with various methods for raising water, and probably after Egypt became a province, many of the machines used by that people were introduced among them, as we have already seen that Vitruvius was well informed upon all the sciences taught in the school of Alexandria, and to him we are indebted for an account of much that otherwise would have been lost. The tympanum he describes might have been long in use, and was calculated not to raise water to any great height, or beyond that of the radius of the wheel, but to lift a large quantity in a small period of time. A shaft or axis turned in a lathe, or made cylindrical by hand, was hooped with iron at each end, to prevent it splitting. This axis was made to turn on tops of posts cased with iron; into this were fitted eight arms or spokes, for the purpose of supporting the rim of the tympanum, which was thus formed; the horizontal face was closely boarded; around it were small apertures about 6 inches in width, to admit the water. When the tympanum was used, it was moored like a vessel, having another wheel attached to the side of it on which a number of men could tread, by which means it was turned round; the water received through the apertures in front of the wheel was elevated by the arms or division thus raised beyond the horizontal position; it flowed towards the axis, at the end of which it ran into a trough prepared to conduct it either to gardens, or to dilute salt in pits.

When this machine was employed to raise water to a higher level, its diameter was increased to correspond with the requisite height. Round the circumference of the wheel were attached small wooden buckets, made water-tight by properly pitching them; the men treading the wheel turned it round, the buckets then mounted to the top full of water, and as they returned with their heads downwards, they discharged their contents into a conduit prepared to receive it. Brazen buckets, each holding a gallon, were attached to a double revolving chain, and when it was required to raise the water still higher, this was mounted on an axis, and made sufficiently long to descend to the lower level; by turning the wheel the chain was turned on the axis, and the buckets were brought to the top, where being inverted, they passed their contents into conduits as before.

Water-mills were introduced at Rome, about 70 years before the Christian æra, as we learn from Strabo, lib. xii., and the first was erected on the Tiber. Antipater, who lived in the time of Cicero, in a beautiful epigram, alludes to one of these, where he addresses the maids who were in the habit of labouring at the mill, and tells them to cease their work, and to retire to rest, to let the birds sing to the ruddy morning, for Ceres had commanded the water-nymphs to perform their task, who, obedient to her commands, threw themselves on the wheel, forced round the axle, and by this means turned the heavy mill.

Vitruvius describes their construction as similar in principle to the tympanum; that round their circumference were fixed floats or paddles, which, when acted upon by the force of the stream, drove the wheel round; attached to this axis was another wheel which had cogs or teeth, and which turned with the water-wheel; a large horizontal wheel, toothed also, and corresponding with it, working on an axis, the upper head of which was made in the form of a dovetail, was inserted in the mill-stone. By this means the teeth of the drum-wheel, which was made fast to the axis, acting on the teeth of the horizontal wheel, produced the revolution of the mill-stones; in the machine a suspended hopper supplied the grain by the same revolution.

Public water-mills seem to have been used in the time of Honorius and Arcadius, about the year A. D. 398, at which time it would seem they were first established.

Mills were erected on the canals and aqueducts which brought water to the city, some of which were stationed round the Mount Janiculum; we are informed that Belisarius placed upon the Tiber boats in which were contrived mills driven by the current of the stream; this was done when the Gothic king Vitiges besieged Rome, and caused the supply of water from the fourteen large aqueducts to be cut off. Procopius, lib. i. says, when the aqueducts were cut off by the enemy, the mills were stopped for want of water; and as cattle could not be found to drive them, the Romans, closely besieged, were deprived of every kind of food, for with the utmost care they could hardly find sufficient for their horses. Belisarius, however, found a remedy: below the bridge which reaches the walls of the Janiculum, he extended ropes well fastened and stretched across the river from both banks; to these he affixed two boats of equal size at the distance of 2 feet from each other, where the current flowed with the greatest velocity under the arch of the bridge, and placing large mill-stones in one of the boats suspended in the middle space a machine by which they were turned. He constructed at certain intervals on the river other machines of the like kind, which, being put in motion by the force of the water, drove as many mills as were necessary to grind provision for the city. These mills, called molina or farinaria, were generally after this time common throughout Europe. Water-wheels put in motion by the current were very early employed to raise water; around the paddle-wheel buckets were attached, which were carried to the top without the aid of treading, and discharged as we have already described.

The Water Screw, still used, is said to have been invented by Archimedes when in Egypt, for the purpose of enabling the inhabitants to free themselves from the stagnant water left in the ditches after the inundation of the Nile, and Vitruvius says, it was contrived on the principle of the screw, and raised water with considerable power, but not so high as the wheel: his instructions for its formation were as follows:—a beam, whose thickness in inches is equal to its length in feet, is made cylindrical, its two circular ends are divided into 4 or 8 equal parts, and as many diameters drawn thereon; these lines are drawn in such a manner, that when the beam is laid in an horizontal position, they correspond with each other. The entire length of the beam is then divided into spaces equal to one-eighth part of the circumference; thus the circular and longitudinal divisions will be equal, and the latter intersecting lines, drawn from one end to the other, will be marked by points. When these lines are accurately drawn, a flexible rule, made of willow, smeared over with pitch, is attached to the first point of intersection, and made to pass obliquely through the remaining intersections of the longitudinal and circular divisions; whence, progressing and winding through each point of intersection, it arrives and stops at the same line from which it started, receding from the first to the eighth point, to which it was first attached. Thus as it progresses through the eight points of the circumference, so it proceeds to the eighth point likewise. Fastening thus similar rules obliquely through the circumferential and the longitudinal intersections, they will form eight channels round

the shaft, in the form of a screw. To these rules of willow others are attached, also smeared with liquid pitch, and to these others, until the thickness of the whole be equal to one-eighth part of the length. The slips or rules fastened all round are saturated with pitch, and bound with iron hoops, in such a manner that the water will not injure them. The ends of the shaft or axle, also strengthened with iron hoops, have iron pivots inserted into them.

On the right and left of the screw are beams, with a cross-piece both at top and bottom, into which is inserted a gudgeon of iron, in which the pivots turn. Men are employed to tread it in the usual way, and by this means the screw is made to revolve. The inclination at which the screw is worked is at an angle of forty-five degrees; for if the length is divided into five parts, three of these will give the height that the head is to be raised; thus four parts will be the perpendicular to the lower mouth. Although the above is the description left us of this instrument or machine, as it was in use by the Romans, in all probability they found out at an after period, that it was not essential to preserve the inclination to one angle, but that it might be either more or less than that of forty-five degrees, for the nearer we approach to a right angle with the cylinder, the more the head of the cylinder may be elevated, and the higher the water will be raised. It is, however, necessary that in inclining it, the channels should decline somewhat from the plane of the horizon, that the water may, as the screw turns, continually descend in its course. When many channels are used, they must of course be made narrower than where there are few, in order to preserve the same inclination, so that less water will be raised by each revolution of the machine.

How the tread-wheel was attached to the cochlea or screw we are not informed, the men employed must have been able to preserve their upright position, and probably an additional wheel was provided for the purpose.

Machine of Ctesibius for raising water to a considerable height. About 150 years before Christ, the mechanical arts had made considerable progress in the school at Alexandria, and many of the principles left by Archimedes were studied more fully, and brought into practice; at this time the common pump seems to have been partially, if not thoroughly, known; and its principles must have been understood before the more complete forcing-pump, which was the invention of Ctesibius. Vitruvius has left us a description of this machine as used in his day. It was made of brass; at the bottom were two buckets, near each other, with pipes annexed in the shape of a fork, united to a basin in the middle. In this basin were valves, neatly fitted to the apertures of the pipes, which, closing the holes, prevented the water, which had been forced into the basin by the pressure of the air, from returning. Above the basin was a cover like an inverted funnel, riveted so securely on it, that the water could not, under any pressure, force it off. On this was fixed an upright pipe, called a trumpet.

Below the lower orifices of the pipes the buckets were furnished with valves, over the openings below.

Pistons made round and smooth, and well oiled, were fastened to the buckets, and worked from above with bars and levers, which, by their repeated alternate action, pressed air into the pipes, and the water being prevented from returning, by the closing of the valves, was forced into the basin through the mouths of the pipes, whence the force of the air, which pressed it against the cover, drove it upwards through the pipe; by this means, water on a lower level might be thrown into a reservoir for the supply of fountains.

Ctesibius, the greatest mechanic of antiquity after Archimedes, invented a clepsydra, or water-clock, an air-gun, and some others, which, as Vitruvius observes, prove that liquids in a state of pressure from the air produce a variety of effects, and for their description refers to the writings of that philosopher, which were extant in his time.

This pump was in all probability the very same in its application of force to the modern fire-engine.

Hydraulic Organs.—These were blown by the action of water, and it has been doubted whether they were not played by the fingers, by means of keys; the description given us of such an organ by Athenæus is that it was invented in the time of Ptolemy Euergetes by Ctesibius, and that the idea was first given by Plato, who invented a clepsydra or water-dial, which played upon pipes the hours of the night at a time when they could not be seen by the index: the descriptions left us by Vitruvius are not sufficiently clear to enable us to comprehend its construction; that by Claudian indicates that it resembled a modern organ, blown by water instead of bellows.

Saw Mills for cutting Slabs of Marble were invented, as Pliny tells us, in Caria, to cut the marble employed to encrust the palace of Mausolus, king of Halicarnassus, as early as 350 years before Christ. The sand which Pliny says was employed for this purpose was the cutting power, and not the saw, which was used for merely passing down the sand, and rubbing it against the marble; the coarser the sand employed, the longer the time necessary to polish the marble, and Cornelius Nepos tells us that Mamurra, who was born at Formia, and employed to superintend the labours of the masons, smiths, and carpenters,

attached to the army of Cæsar in Gaul, was the first Roman who covered the walls of his house with slabs of marble.

Measuring Distances when Travelling, Vitruvius says, was discovered by the ancients, and found useful in his time; his account exhibits the manner in which such mechanism was employed at sea and on land. When adapted to a chariot or travelling carriage, the wheels were made of such a diameter, that every revolution would advance the carriage 12½ feet, thus 400 revolutions passed over 5000 feet, or a Roman mile; the diameter of the wheels was therefore nearly 4 feet. A drum wheel was securely fixed to the inner side of the nave of the wheel, which had one small tooth projecting beyond the face of its circumference; and on the body of the chariot was a small box with a drum wheel, placed so as to revolve perpendicularly, and fastened to an axle. This latter wheel was equally divided, on its edge, into 400 parts or teeth, which corresponded with the teeth of the lower drum wheel; besides this, the upper drum wheel had on its side one tooth projecting out before the others. Above, in a third enclosure, was another horizontal wheel, similarly toothed, and which corresponded with that tooth which was fixed to the side of the second wheel. In the third wheel, just described, were as many holes as are equal to the number of miles in an ordinary day's journey. In all the holes were placed small balls, and in the box or lining was made a hole, having a channel, through which each ball might fall into the box of the chariot, and the brazen vessel placed in it: as the wheel turned round, it acted on the first drum wheel, the tooth of which, in every revolution, striking the tooth of the upper wheel, caused it to move on, so that when the lower wheel had revolved 400 times, the upper wheel had revolved but once, and its tooth, on the side, would have acted on only one tooth of the horizontal wheel; 400 revolutions of the lower wheel caused the upper wheel to turn but once, and thus showed that 5000 feet, or 1000 paces, had been performed. By the dropping the balls, and the noise they made, it was known when they had performed a mile, and at the end of every day's journey, the number of balls collected in the bottom showed the number of miles passed over.

In navigation, nearly the same means were used; but an axis passed across the vessel, projecting over each side; to this were attached wheels four feet in diameter, with paddles dipping into the water. That part of the axis within the vessel had a wheel with a single tooth standing out beyond its face, at which place a box was fixed with a wheel inside it having 400 teeth, equal and corresponding to the tooth of the first wheel, fixed on the axis. On the side of this also, projecting from its face, was another tooth. Above, in a box, was enclosed another horizontal wheel, also toothed, to correspond to the tooth fastened to the side of the vertical wheel, and which in every revolution, working in the teeth of the horizontal wheel, and striking one each time, caused it to turn round. In this horizontal wheel were holes, wherein the round balls were placed, and in the box of the wheel was a hole with a channel in it, through which the ball descending fell into the brazen vase, and made it sound. A vessel impelled either by oars or by the wind gave motion to the paddle wheels, which, driving back the water forced against them, turned the axle round, and the drum wheel followed, whose teeth in every revolution acted on the tooth of the second wheel, and produced moderate revolutions. When the wheels were carried round by the paddles 400 times, the horizontal wheel had made one revolution, by the striking of that tooth on the side of the vertical wheel, and thus in the turning caused by the horizontal wheel, every time it brought a ball to the hole it fell through the channel. By sound and number were found the number of miles the ship had passed.

In the early Italian editions of Vitruvius, particularly that by Cæsar Cesarinus, woodcuts exhibit these paddle-wheels attached to the sides of the vessels.

Hydraulic architecture is greatly indebted to the Italian engineers, who have been successively employed in draining the marshes of Italy, confining the rivers to their natural bounds, and the ocean to its limits; before the seventeenth century there were scarcely any principles laid down to direct the civil engineer, and Europe could hardly boast of any eminent man in that profession. Rome had left marks enough of her greatness: as far as construction went, or the handling of materials, there could be no want of models to guide the labours of the artificers; in building, enough was to be found to imitate, both in the science and the art. But hydraulic architecture had been neglected; the rivers, in consequence, were left to pursue their natural course, their beds became elevated, and their openings to the sea silted up: all the ancient harbours were for the most part destroyed or unfit for the reception of vessels of larger burthen, which commerce had introduced.

Lombardy, the richest district in all Italy, and with a soil more fertile than any other in Europe, is watered by the Po, which receives its supply from both the Alps and Apennines, and has its course for upwards of a hundred leagues through Sardinica, Pavia, Placentia, Cremona, Mantua, and Ferrara to the Adriatic Sea; its importance is so great, that it is navigable to Turin.

The snows which cover the mountains that bound Lombardy during the summer afford

it abundant water to irrigate the lands of Piedmont, where this practice has been adopted from time immemorial.

Near Bologna, Ferrara, and towards the Adriatic Sea, the land is often under water, and the inhabitants of this district are subject to breathe an impure and malignant air in consequence; this is chiefly owing to the attempts made in the middle ages to keep out the Po, by constantly throwing up dykes, for the purpose of penning back the water in the river; this naturally, in the course of years, from the deposit, tended to elevate the bed considerably above the country it flowed through.

At the mouth of the Po, vegetation flourished amidst these deposits and overflows, producing the worst kinds of malaria, and that portion of the coast of the Adriatic, which intervenes between Mount Pesaro and the port of Brondolo, and which formerly exhibited a deep hollow curve for its section, was by the alluvium elevated to a considerable height; in consequence all the roads were rendered impassable, and the various streams which flowed into the sea, at this portion of the coast, as the Po at Goro, the ancient Po of Primaro, the Lamone, the Ronio, the Savio, Usa, Marrechia, and many others, which brought down in their course a quantity of deposit, had their beds considerably elevated; this occasioned the banks which confined them to be raised in proportion, and when these from neglect gave way, in the time of floods, the whole country became one vast lagune or swamp.

Ravenna contained upwards of 14,000 inhabitants, and was founded, according to Strabo, by a colony of Thessalians, on the borders of the sea, from which it is now, in consequence of the deposit from these rivers, more than two leagues distant, and that place, which was a port in the time of Augustus, and served him to assemble his fleet, is now land. Even so late as the time of Theodoric, it was a place of so much importance, that after his conquest of Italy, he made it his capital, and highly embellished it; it contains his tomb, which is a curious structure of Istrian stone, 34 feet in diameter, covered by a single block, placed 40 feet above the floor; the lower part of this circular edifice is now filled with water.

Ravenna was built, like Venice, in the middle of the waters, and by the Romans it was united to the main land; it is now situated between the mouths of the ancient Po of Primaro, of those of Lamone, of the Ronio, and of the Montone, and this once celebrated marine establishment is now an extensive marsh.

The lagunes of Commachio once formed a portion of the sea; they are now situated between the ancient beds of the Po of Primaro and of the Po of Volano. When the tongue of land, or bank, which separates these lagunes from the sea was thrown up is not known. Neglect during the middle ages of these great and important rivers was the chief cause of the changes which have taken place on this coast; their deposits have filled up the sea where they have discharged themselves: Ravenna is now 8000, Rimini 1500, and Adria 32,000 metres from the coast; and each of these places ranked as ports in the time of the Romans.

Rimini was the spot on which the Æmilian and Flaminian roads terminated, and in the time of Augustus it was a port of importance; here was his arch of triumph and his bridge.

Upwards of 160 square leagues of country was desolated by these overflowings of the various rivers in the sixteenth century, and it was a constant cause of dispute between the inhabitants of Bologna and those of Ferrara.

In the twelfth century the Po had passed near Ferrara, and in 1155 it changed its course, and in the year 1600 it was deemed advisable to separate the Panaro and Rheno, which flowed over its ancient bed, called the Po di Primaro, and which inundated the valleys of Commachio. About 1604, the Pope ordered that the Rheno should be turned into the valley of Santa Martina, but all that could be done could not prevent their being overflowed, for the banks gave way several times, and a very considerable sum of money was spent to no purpose. These terrible inundations alarmed the whole of the inhabitants of this part of Italy; the evils were daily increasing, and the most eminent scholars of the day, (for there were no engineers,) were consulted upon the occasion; it may be considered highly fortunate for Europe and the world in general, that these disasters directed the labours of the greatest philosophers of the age, when science began to revive, to the study of hydraulic architecture: all we at present know has its origin in their experiments; all the useful inventions applicable to modern practice, we owe to the writings of Francesco Mengotti, Mario Lorgna, Pietro Zuliani, Francesco Focacci, Antonio Tandini, Isidoro Bernareggi, Barnabita, Giovambatista Masetti, Vittorio Fossombroni, Pietro Paoli, Antonio Lecchi, Bernardino Ferrari, Giuseppe Bruschetti, Carlo Perea, Eustachio Manfredi, Giovanni Poleri, Paolo Frisio, Tommaso Perelli, Giovanni Bacciali, Eustachio Zanotti, Ruggiero Bosvich, Leonardo Zimines, Bernardino Zendrini, Dominico Guglielmini, Galileo Galilei, Benedetto Castelli, Alfonso Borelli, Evangelista Torricelli, Guido Grandi, Famiano Mechelini, Tommaso Narducci, Lorenzo Albozi, Geminano Mon-

tanari, and several others, which are all printed, and form almost an encyclopædia on the subject.

Galileo Galilei was a native of Pisa, and born in the year 1564; on one of his visits to the beautiful Duomo, at an early age, he observed the swinging of the large chandelier, and from thence he set about constructing the first pendulum. Mathematics at this time was at a very low condition, not only in Italy, but throughout Europe; but Euclid and Archimedes were now generally revived and studied by all who had any pretensions to science; after Galileo had studied the writings of the latter, he published his first work, which was an essay on the hydrostatic balance, in which he proves himself thoroughly acquainted with the principles of specific gravity. His learning then became generally known, and in the year 1589 he was named professor of mathematics at Pisa, where he received a salary of sixty crowns per annum. The phenomena of nature now formed his chief study, and he began to inquire into the mechanical doctrines of Aristotle, although he can hardly be considered the first who impugned his high authority. Leonardo da Vinci had indulged in investigations which astonished his cotemporaries, and which were entirely unknown to the philosophers of the time.

Galileo succeeded Moleti in the professor's chair at Padua in 1588, and soon after took up the study of the thermometer, which was to a certain extent the result of the Greek mathematician Hero's contrivances. Galileo's tube was made of glass, the bulb having the air expelled by heat, and then filled with water; after which the degrees were marked upon it, which indicated the expansion of the air when subjected to a change or increase of temperature.

In the year 1609, he invented the telescope, and three years afterwards published his Discourse on Floating Bodies, after which he turned his attention to the sucking-pump, and when he found it would not act beyond a certain depth, he imagined some injury had occurred to it, and sent it to the maker to have it repaired. The maker assured him that no pump would raise water beyond the depth of eighteen cubits, when Galileo observed, in his explanation upon this phenomenon, that a rod or column of water, when raised to the height of eighteen cubits in a pump, its weight overpowers the attraction of the piston and the cohesion of the particles of the fluid. He died in 1642.

Evangelista Torricelli, born in 1608, was the pupil of Galileo at the same time with Castelli: he became highly interested on the subject of the pump, and made it his particular study; the year after Galileo's death, he made an experiment upon the vacuum left between the piston of a pump and the water which it raised; after which he filled a glass tube with mercury, hermetically sealed at one end, and closed at the other with his finger, and then inverted it into a basin of mercury, when he was surprised to find, upon the withdrawal of his finger, that the mercury stood twenty-nine inches in the tube. This indicated at once that the column of mercury was maintained by the weight of the column of atmosphere, and that the thirty-three feet of water in the pipe of the sucking-pump was supported in the same manner as the twenty-nine inches of mercury.

Considerable advance was made in the science of hydrodynamics by this able disciple of Galileo. He was one of the first who showed that when water is let out at the side or bottom of a vessel, it issues with the same velocity as that which a body would acquire by falling from the surface of the fluid to the orifice.

Torricelli gave us the means whereby we might measure the density of the atmosphere, and constructed the first barometer. But it is from his treatise, "De Motu Gravium naturaliter accelerato," that we learn, for the first time, something of the complex theory which regulates the motion of fluids, when the orifice has a magnitude which is considerable compared with the section of the vessel taken horizontally.

Benedetto Castelli was born at Breccia in the year 1577; he was among the distinguished disciples of Galileo, and may be considered as the originator of a new theory of hydraulics, relative to running waters, on which subject he compiled a treatise, "Della Mesura dell' Acque correnti," published in 1638.

Urban VIII. having requested him to report upon the means of completing the several works which were then in progress to drain various parts of the papal dominions, was the cause of his writing the above treatise. It contains several explanations of various phenomena relative to rivers; and he states, what some have hesitated to admit, that the absolute velocity is proportional to the declivity of the bed, or to the height of the water. He died at Rome, 1644.

Dominico Guglielmini was born at Bologna, 1655: at the age of thirty he had so distinguished himself in the various branches of science then studied, that he was appointed chief engineer of the territory belonging to the Bolognese,—a very important office, as it had under its superintendence the confining of the numerous rivers which intersect that country in all directions, and which frequently, if neglected, subjected it to inundations. In the year 1690, he was made professor of mathematics, and four years afterwards a new chair was created for him, under the title of that of Hydrometry, which, from that period,

was accounted deserving of being ranked among the cultivated sciences. Among his writings that "Della Natura de Fiumi," published in 1697, obtained him the greatest celebrity. It treats of the equilibrium of fluids, the origin of springs, the motion of running water, either falling perpendicularly or on an inclined plane, together with the consequences of friction, the resistance offered by the air, &c.; of the beds of rivers, their breadth, width, and depth, as well as slope, the uniting of rivers, as well as their discharge into the sea, the consequence of increase after heavy rains, the supplying artificial canals, the drainage of wet lands, and the precautions that should be taken when the course of a river is altered or shortened.

Guglielmini, in this work, puts forth a variety of new suggestions well deserving the attention of all who profess hydraulic architecture. He devoted his life to the pursuit of the sciences: his naturally robust constitution yielded to over-excitement, and he died at the age of fifty-four, in the year 1710.

Giovanni Poleni (Marchese) was born at Venice in the year 1683, and at an early age he distinguished himself in the acquirements of the sciences, and was entrusted by the Venetian state with the care of all the hydraulic works. His eminence was admitted by those sovereigns whose territories were subject to inundations throughout Italy, and he was frequently selected as the arbitrator to decide upon the conflicting opinions which arose when a river running through one state did injury to another. All his decisions were given in a manner to satisfy, as well as to increase his reputation, and in 1719, we find him appointed to succeed Niccola Bernoulli in the chair of mathematics at Padua.

Poleni was one of the most celebrated writers on hydraulics; and his work, "Del Moto misto dell' Acqua," is highly interesting, although the subject, perhaps, had been ably treated before by some of the Italian philosophers. He in this work, however, has some ingenious ideas; he supposes the bed of a river to be a rectangular canal, and a perpendicular section of it an orifice, and calls that dead water which is between the surface and a certain point, where all the fluid molecules are in equilibrium, which he supposes are governed by the same laws as solid bodies.

The water which is between this certain point and the bottom of the canal is called living water. And he further considers that the motion of the water which flows through the orifice is occasioned by the action which the living water acquires from its fall, and from the pressure exerted by the dead water, and thus that motion is produced by the mixed waters.

Another of his essays is entitled "Delle Pescaie o Cateratte dei lati convergente, &c." in which are many valuable observations; but his principal work was that which appeared in the year 1718, entitled "De Castellis per quæ derivantur Fluviorum Acquæ."

He died 1761, aged sixty-eight.

Eustachio Manfredi, was born at Bologna in the year 1674, and died in 1739; he published some valuable remarks in an edition of the works of Guglielmini on Rivers, also another entitled "Opere Idraulicke," which relates chiefly to the opinions of the various engineers upon the proposed change in the course of the Po and the Rheno.

Manfredi was appointed by the Bolognese in 1704 their chief engineer, was equally eminent with his predecessor Guglielmini, whom he succeeded.

Bernardo Zendrini, was born near Breccia in 1679, and died in 1747; received his instructions under Dominico Guglielmini at the university of Padua, where he became learned in mathematics, astronomy, and medicine, which latter he practised for some time as a profession; among his first scientific treatises was one on the hurricane which happened at Venice in 1708, in which he enters upon the weight and electricity of the air; the origin and varieties of gas; the cause of wind, &c. He then excited public attention by his analysis of a problem which still continues to present extreme difficulties,—if a fluid in motion is confined within a given channel, the sides of which are susceptible of erosion, their surface will take the form suitable to the establishment of the resistance and the erosive power of the fluid; this depends on the relation between the rapidity of the molecules and the nature of the material that compose the sides. A curved surface is the usual form they acquire; and the hypothesis of the transverse section being polygonal, with a flat bed and sloping sides, he says is not that which nature carves out. To have regard to the rapidity of fluid threads which traverse this section, it must not be supposed that they augment from the bottom to the surface, where they would attain their maximum force; they on the contrary augment from the entire surface as well as the sides, to a thread situated somewhere in the interior of the fluid mass, the position of which depends on its form and other circumstances. A memoir upon this subject was published in 1715, entitled "Modo do ritrovare ne' Fiumi la Linea di Corrosione." It contains a description of a very simple instrument to ascertain the various rapidity of the current. The plains which lie between the towns of Bologna and Ferrara being at this time inundated by the Reno, the inhabitants of Bologna wished to change the mouth of the river to beyond Ferrara into the Po of Lombardy, and the most celebrated Italian engineers, Castelli Guglielmini, Gabriel and Eustachio Manfredi, supported them in their views in opposition to the inhabitants of

Ferrara, who were desirous of conducting the Rheno to the southern extremity of the Lake Comacchio, and carrying its waters to the sea through the Po di Primaro.

Zendrini was invited, on the death of these celebrated engineers, to confute the opinions which they had given in their reports, and which the inhabitants of Bologna were inclined to adopt: on this occasion appeared his celebrated work, entitled "Considerazioni sopra la Scienza delle Acque correnti, e sopra la Storia naturale del Po;" this was published in 1717. After this work appeared, the Duke of Modena appointed him his chief engineer; and in the year 1720, by the decrees of Venice, he was nominated superintendent of the waters, rivers, canals, lagunes, and ports belonging to that city. This republic always appointed two of its most eminent philosophers to act as engineers, and maintain the watercourses of the city in proper condition: some of these were men famous for their knowledge in hydraulics; among them was Christopher Sabbadino, nominated Prote in the year 1542.

Zendrini occupied himself during the superintendence of these important works at Venice with compiling an account of the ancient and modern state of the lagunes, which was published about sixty-four years after his death; it is entitled "Memorie storiche del' Stato, antico e moderno, delle Lagune di Venezia, &c.," printed at Padua, in two quarto volumes.

This history comprises the period between 1300 and 1700; Zendrini cites a letter of Cassiodorus, which gives a tolerably exact account of the state of the lagunes and Venice between the fifth and sixth centuries, which is highly interesting; and the numerous plates given are curious with regard to levels, and the means adopted to execute the different works which were required to keep the canals open.

Zendrini was employed to survey the country round the port of Viareggio in the republic of Lucca; his report was printed at the time. In it are many observations on the level of the sea; he commenced and executed works in this part of Italy, which ameliorated the condition and health of the inhabitants; the good effects of which were destroyed by the intestine animosities that happened afterwards.

Clement XII. employed him in 1731, to report upon the state of the country about Ravenna, which was occasionally inundated by the waters of the Roneo and Montone; these rivers he turned into new channels, and in 1741 published at Venice an account of what he had performed.

Soon afterwards appeared his famous work, "Delle Acque correnti," to which subsequently was added the work entitled "Relazione per la Diversione de Fiumi Roneo e Montone."

In the first of these the author gives general observations on the nature of fluids, treats of their motion when issuing from reservoirs by simple orifices, as well as by pipes; he then takes up the subject of running water, the methods adopted to ascertain its velocity, and its effects upon the beds and banks of rivers or canals; he also treats of the breaking down of dykes and dams, the means by which these effects may be prevented, and the different methods usually adopted to divide a stream; the draining of lands: a description is added of various improvements, that in his opinion might be made in some hydraulic machines.

This work shows distinctly the state of hydraulic knowledge at the time of its publication; it rectifies many ancient theories, and is enriched with ideas new at the time they were made known; it was justly considered a *chef-d'œuvre* by his contemporaries, and, notwithstanding the progress that has been made since on these subjects, it is a book which every intelligent engineer should possess. Zendrini died in the year 1747, and the Venetian senate decreed him great honours.

Lazarettos in Italy.—That at Genoa is near the sea, and comprises two spacious courts, one of which is devoted to goods which are infected, and the other to those which may or may not be so. In the middle of each of these courts is a chapel; three sides are surrounded by buildings three stories in height; the fourth contains the apartments of the physicians and medical attendants. At the entrance is a guard-house; three sides of the courts are occupied by corridors, 10 feet 9 inches in width, separated by doors, so that the crew and passengers of different vessels may be kept apart. From these corridors the rooms are entered, which are occupied by those in quarantine; they are 15 feet 7 inches, by 14 feet 3 inches, and 11 feet 6 inches in height.

On the upper floors there are in front thirty-six rooms, besides twelve occupied by the governor; on one side are ten, on the other eleven rooms, all of one size, viz. 16 feet 9, by 14 feet 9, and 11 feet 6 inches in height; each has two windows opposite one another, so that a thorough ventilation can be obtained; they are placed at a height of 6 feet above the floor, and are 4 feet by 3 feet. The floors are paved with brick, and the rooms are vaulted; they have a fireplace in one angle, and in another a small closet containing the urinal and drain. All these upper rooms open into a spacious corridor, 11 feet in width, the windows of which are towards the court; and there are also doors so contrived, that they can shut off three or four rooms as may be required.

The windows are barred with iron and have shutters, but are not glazed.

On the second floor are three ranges of warehouses, 16 feet 6 inches in width, approached by brick steps from the outside; the floors are of stone, and the windows are 3 feet by 2 feet 9 inches.

In the front are three elevated towers, and through the court flows a clear stream of spring water, which is conducted from the neighbouring mountains; it then runs through all the sewers, and scours the drains most effectually.

Leghorn Lazarettos.—There are three; that called San Leopoldo is very conveniently arranged; at the upper end is the statue of the Grand Duke, at whose expense the buildings were constructed; it has served as a model for all others in Italy. It contains spacious rooms, and every sort of accommodation for those whose ill fortune consigns them to the necessity of a purification; the several courts are so placed, that the cargoes and crews of

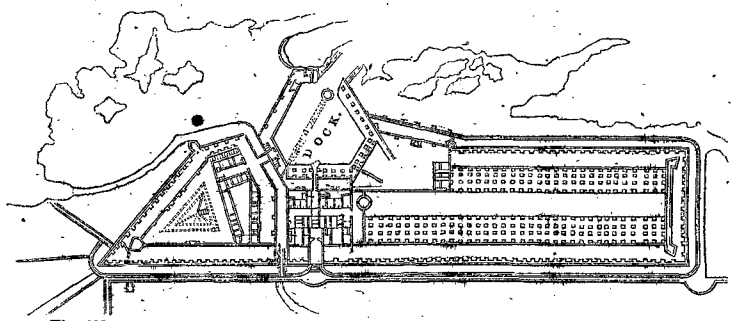


Fig. 233. LAZARETTO AT LEGHORN.

the vessels arriving at the port may all be separately lodged, though they are not so. Isolated buildings arranged along an open shore, or on an island in the ocean, afford the best guarantee for the continued health of the individuals within them; should infection be brought by the cargoes of one vessel, it is highly necessary that those who without cause are obliged to undergo the ordeal of a lazaretto should not be exposed to the infection they have escaped by their own caution, or from being placed in more fortunate circumstances.

The Lazaretto at Varignano in the Bay of Spezzia is situated on a promontory stretching into the sea, and forming a beautiful object on the coast. The court nearest the gulf is for aired goods, as are the buildings on each side of the second court. A wide walk divides

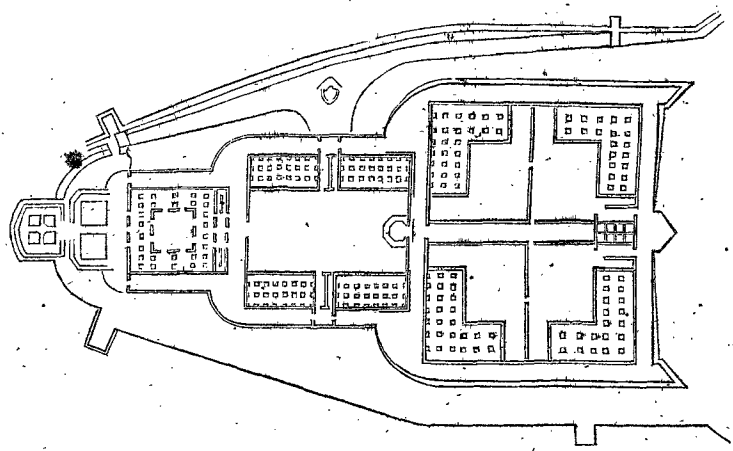


Fig. 234. LAZARETTO AT VARIGNANO.

the great square inland, and a wall at right angles again subdivides it into four courts, one of which is devoted to the infirmary, and the others to infected goods. Around the whole is a wall and apartments for the officers and attendants.

The great defect of this establishment is, that the several lodgings set out for the crews

are built against the outer walls, which renders the ventilation imperfect, windows not being permitted on the outside.

The docks for the shipping are convenient, and there are plentiful supplies of fresh water; but the want of a free circulation of air, and the too great proximity of the different buildings, are serious objections.

Great attention and skill is demanded in the selection of a site, as well as in the arrangement of hospitals of this kind.

In Italy, engineering works continued to be carried on with great success: in Rome *la santa*, Napoli *la gentile*, Genoa *la superba*, Milano *la grande*, Ferenze *la bella*, Bologna *la grassa*, Ravenna *l' antica*, Padua *la dotta*, and Venezia *la ricca*, all can boast of objects worthy the attention of an engineer. The latter city deserves admiration for the various difficulties overcome in laying the foundations for the noble buildings it contains. The province of the Roman Venetia was bounded by the Adda, the Rhætian and Julian Alps, and the Po. About 450 years before Christ, the inhabitants of Aquileia and Padua, driven out by the Huns under Attila, took refuge in the islands along the coast, and laid the first foundations of the future Venice, on the island of Ripa Alta or Rialto. In A.D. 570, the patriarch of Aquileia fled before the Lombards with his flock, and settled himself at Grado, afterwards called New Aquileia; his successors became the first ecclesiastical primates, and about the middle of the fifteenth century they removed to Venice.

The modern city is built upon two islands, separated from each other by the great serpentine canal, which is crossed by one bridge, called the Rialto; its total area has been estimated at one square mile and a half. The two islands are subdivided by many smaller canals at right angles with the larger, and as the streets or alleys are seldom more than 8 or 9 feet wide, the communication from house to house is chiefly carried on by means of boats, almost every doorway having a landing stair at the water side.

The houses are of brick, or of Istrian marble, which bears a fine polish; the floors are composed of fine plaster and pounded brick, into which, when in a soft state, black and white marbles are imbedded, and when dry, are polished; the foundations of the buildings are either upon piles or masses of concrete.

The entrance of the Laguna is guarded by the fort of Lido, distant about two or three miles from Venice; the Laguna is separated from the sea by a line of narrow sandy islands, which have required the most vigilant attention, in order to prevent the embankments or barriers from being forced into the channel. There are two other passages through these narrow sandy deposits, one at the port of Malamocco, and the other at Chiozza, where massive stone walls have been constructed to defend it against the action of the sea.

Within these sand-banks, produced by the deposits brought into the Adriatic by the several mouths of the Po, the Laguna forms an extensive bay, a great portion of which is dry at low water; the tide rises about 3 or 4 feet, and occasions a current sufficient to work the mills on the island of San Georgio Maggiore. To keep the various canals open, a dredging machine was used at a very early period, which underwent many changes and improvements before its introduction became general.

Cassiodorus, appointed præfect of Venice by the Emperor Theodoric, has left us an interesting account of the lagunes at the commencement of the sixth century, when the chief exports were fish and salt.

From the summit of the lofty Campanile in the Piazza San Marco, a fine view of the city rising amidst the Laguna is obtained. To the north lies the Julian Alps, reaching from the Lake of Garda to Trieste, often covered with snow; to the west is Monte Selice, formed of porphyry and trap, probably of volcanic origin.

The arsenal was a noble establishment, and contained slips for ship-building, and arrangements for the manufacture of all that was required for their equipment and efficiency in time of war. Here the *camel* was first used for floating large vessels out of the Laguna, which consisted of four cases, with concave sides, so made as to embrace the whole ship; they were towed under it, and united securely together; the water was then pumped out of the camel, and it became sufficiently buoyant to float its burthen in very shallow water; such a method was adopted by the ancients to move obelisks and heavy masses, where there was not depth enough for their large craft to navigate.

In constructing the foundations at Venice, every precaution was taken to collect the waters which rise from the springs at the bottom of the lagunes; they are conducted into a basin or well left to receive them, in the bed of concrete upon which the walls were built; where a spring did not occur, the well was converted into a tank to receive that which fell from the roofs of the buildings during the rainy season. These supplies, however, frequently failed, and it was then conveyed in boats from the shores of the main land, and disposed of to the inhabitants. Trade and commerce have departed from Venice, and its population is in consequence greatly diminished; but the city remains, to interest the historian, the architect, and the civil engineer. The finest designs of Palladio, and the manner in which he laid his foundations, may be seen in various parts of the city, and form the best commentary upon that portion of his treatise on building. All the chief men of

Italy, celebrated for their acquirements in hydraulic architecture, met with employment and encouragement in Venice, and she must for centuries have been a school for the instruction of engineers.

Before we leave this portion of our subject, and proceed with an account of the works executed since the destruction of the eastern and western empire, it is due to the engineers of Italy to acknowledge how much we are indebted to them for the science handed down through the middle ages, upon which our modern practice in the arts of construction is founded.

The ancient writers are scanty in such observations as practical men seek after, and it is to be regretted that information upon many important and vast undertakings of the emperors of Rome is not more fully given.

Cities, harbours, roads, bridges, supplies of water, baths, drainage of vast districts, public edifices of all denominations, were laid out and executed in a manner never yet surpassed, the majestic ruins of which are spread far and wide for our wonder and admiration. The whole circle of the building arts was employed in deep seas, in rapid rivers, and on most difficult sites, where foundations were raised to bear the extraordinary weights imposed upon them. We must blush at the expensive but too often ill-directed efforts of the present day, when we reflect on the well-proportioned and majestic structures which still remain in and around the Imperial city. It must also be admitted, that we have not improved on their knowledge of construction; and if Vitruvius, to whom we have so often referred, be studied by a mind bringing with it a spirit and judgment equal to the information found in that author, it will be convinced that there is nothing new in the works of modern times. The builders of later generations too generally present to us only the lifeless form, while their brethren of yore stamped on their erections all the glow and beauty of vitality.

About the middle of the fifteenth century, the arts were again encouraged. Leon Battista Alberti wrote his treatise, "De Re Ædificatoria," which, from its close resemblance to the author alluded to, proves that Vitruvius was held in the highest consideration. When Alberti was employed by Pope Nicholas V. to repair the aqueducts at Rome, particularly that of Aqua Virgine, he devoted himself to the study of Frontinus, and acquired a thorough knowledge of the principles which guided the ancient engineers.

Hydraulic architecture, after the splendid discoveries of Galileo and his successors, became more refined by the abstract and mathematical reasoning to which it was subjected; but many of the calculations were formed upon erroneous and inefficient data, and consequently have become of little value, — a very common result when such calculations are not accompanied by a practical acquaintance with the subject in question. Theory and practice must go hand in hand; the calculations of the one must be based on the experience of the other, while the active energies of the practical man may be materially assisted by the silent process of well-directed reflection. The authors of Italy, during the fifteenth and seventeenth centuries, revived the writings of the classic period; and in commenting upon the subjects they described, Palladio and other practical men were required to provide illustrations: thus were the bridges of Cæsar, Trajan, and the emperors brought under the notice of the engineers of that period. The baths of the Romans also met with their share of enquiry, and little was left upon these subjects to the moderns in the way of interpretation; they had only to apply their reasoning to what remained of the structures.

To the Romans we stand indebted for the knowledge that is interesting to us as a maritime nation. They first established in Britain ports and havens, marked out and formed roads from one end of our island to the other, which excite wonder even in the present day for the straightness of their course, and the solid manner in which many of them are executed. They established beacons on our coast, remains of which may be traced on some of the heights which girt our isle; within the circuit of the walls of Dover Castle, their pharos is still shown. It would be impossible to do justice to the people of this mighty nation: wherever they established themselves they introduced improvement, drained marshes, cleared lands, brought them into cultivation, and encouraged commerce.

Their stone cutting and artificers' work of all kinds have served us for models; our very nomenclature upon the subject is derived from them. Of the solidity of their constructions we have ample proof; and had they been left to the hand of Time alone, we might have derived many useful lessons from the study of those structures over whose ruins we now linger with wondering regret.

CHAP. V.

ENGINEERING WORKS IN HOLLAND AND GERMANY.

THE level of a great portion of Holland being below that of the sea, the construction of dykes, or banks, to keep out the water has given employment to a vast number of individuals, and called forth the ingenuity of the greatest mathematicians of the age, to economise their labours, or to direct them in the most efficient manner.

The dykes are in many places raised 30 feet above the ordinary level of the country, and have sufficient width at the summit to form a roadway: towards the sea, both above and below the level of the action of the water, is a strong matting of flags, or reeds, which retains the earth towards the summit of the mound, and on the land side, piles and planking are adopted, to give the requisite strength; these are filled in with stones covered with earth and turfed. The matting of flags, of which we have no notice before the end of the sixteenth century, has been found very successful: they are twisted together in bundles, and laid horizontally, at distances of three or four yards from each other, and then secured to the ground by wooden stakes, or by large stones. Above these layers of flags piles are driven in, to which a number is attached, that the surveyors or engineers entrusted with the maintenance of the banks may refer. Enormous sums of money have been expended on these sea-dykes, and when the sea rises to a great height, the inhabitants are obliged to cover them with sails to prevent their washing away: the water which passes over them is afterwards pumped out, either by windmills or other means.

The Rhine, the Leck, the Vaert, the Yssel, the Maes, and other rivers which are discharged into the sea on the coast of Holland, have their banks maintained in a similar manner. The great Lake of Haarlem, 12 miles long and 9 broad, situate between the towns of Haarlem, Amsterdam, and Leyden, is remarkable for its sluice, which effectually resists the inroads of the sea.

Where the canals in these districts do not unite but are separated by a dyke, there are contrivances to transport vessels from one to the other by means of wheels and rollers.

As a great portion of the richest land in Holland has been gained from the sea, it is of the highest interest to inquire by what means this was effected: the districts in the north consist of the Zype, the Beenister, the Wormer, and Schermeer. The first was commenced about the beginning of the sixteenth century, when an extremely strong embankment or mole, formed of timber, filled in with large stones and covered with earth, was constructed at an enormous cost.

The draining the lakes of Purmur and Beenister were the next operations carried on, when many thousand acres of the most profitable land in Europe were redeemed, planted with orchards, converted into garden ground and meadow. Dugdale, in his "History of Embanking," gives it as his opinion, that Holland consisted of a three-fold earth; viz. sandy to the sea, clay to the rivers, and moorish in other places, and that it was the gift of the ocean, and of the rivers which pass through it, as was Egypt of the Nile; and, quoting the historian Nannius, states, that "Holland was the gift of the north wind and of the Rhine, and was in the beginning no other than a more high place than ordinary, over which the tides do usually flow; whereby through the increase of the sands which the north winds, fiercely agitating the waves, stirred up, it first grew to be a shore, and afterwards raised those sandy heaps, which we daily see both to be made and destroyed." And further, "that the waters of the Rhine, by this stop, being kept up as it were with a bank, settled the mud brought down by the stream about the shores, and so by long and frequent inundations produced those pastures. For it cannot be imagined, saith Bertius, that the face of this country was always as it now is discerned to be, or that it soon arose from its former condition, unto this fertile and pleasant state, in which we behold it at present; there being much time, extraordinary labour, excessive study, vast expenses, and great diligence necessary thereto. Nature therefore first inviting, the inhabitants bordering near unto it to make those banks of sand, as a defence against the north wind, and necessity also spurring them on (than which no master is more ingenious and powerful), in time those their accustomed endeavours became a second nature to them, it being not unusual to see the very boys and girls, when they come to the sea-side to recreate themselves, to put off their stockings and shoes, and taking up the sand with their fingers to make walls therewith against the ocean, within which, thus encompassing themselves, they disperse the force of the waves."

The Batavians first occupied these districts, then the Danes and Normans, and afterwards the Saxons; to each of these people some praise is due for the manner in which the first embankments have been maintained, and "for the performance of these eminent works,"

continues Dugdale, "it required extraordinary knowledge and skill, which ancient times had not attained to, and foreign nations now admire. The engines of several kinds made use of for raising the water and casting it off were framed by men of singular judgments in mathematical learning, and suitable to the depth of the water, or opportune for carrying it away. Friseland, which lies very much beneath the surface of the ocean, is preserved by the wall raised in 1567, by a Portuguese in the employ of Philip II., King of Spain; the author before alluded to asserts that it would require a volume to give an account of all the works of this nature in the Low Countries, and the several banks, ditches, and sluices.

The provinces of Belgium which formed a portion of Gaul were in the time of Cæsar full of woods and fens, which latter were not effectually drained till the work was taken in hand by Baldwin I., who married Judith, daughter of Charles the Bald.

In the year 1169, Floris, earl of Holland, demanding the Isle of Walcheren, in Zealand, from Philip, earl of Flanders, obtained it, on condition that he sent to Count Philip 1000 men expert in making ditches, to stop the breach near unto Dam or Sluse, whereby the country was drowned at every high sea; "the which the Flemings could by no means fill up, neither with wood, nor any other matter, for that all sunk as in a gulf without a bottom, whereby in process of time Bruges and all under its jurisdiction had been in danger of being lost by inundation, and to become all sea if it were not speedily repaired. Whereupon the Count Floris sent the best workmen that he could find in his territories, who being come to the place, they found a great hole, near unto this dam, and at the entrance thereof a sea-dog, that for six days together did nothing but cry and howl very terribly. They not knowing what it might signify, resolved to cast this dog into that hole, whereupon a mad-headed Hollander, getting into the bottom of the dyke, took the dog by the tail, and cast him into the midst of the gulf with earth and turf after him, so as, finding a bottom, they filled it up by little and little." They named the place in consequence Hontsdam, or Dog's Sluice; *dam*, in Flemish signifying a sluice, and *hont*, a dog. The town still has a dog in its armorial bearings.

The banks from Dam to Sluse thus rescued from the sea, in 1180, all the land that had been submerged.

At Antwerp the Emperor Napoleon raised on the banks of the Scheldt, which is here upwards of 2000 feet in breadth, and 40 feet in depth, dockyards, slips for ship-building, and one of the most magnificent quays in Europe. Engineers were sent from France to conduct these works, upon which vast sums of money were expended, and Antwerp became one of the most important ports on the coast; it is situated in an extreme plain on the eastern bank of the Scheldt, and is divided by eight canals which traverse the city, on which are warehouses for the reception of goods. The exchange, which was the model for that constructed by Sir Thomas Gresham in London, and the celebrated warehouse or magazine, in which all the merchandise that once enriched this distinguished city was deposited, still remain. Some of the bridges erected in Germany deserve to be mentioned, and we shall commence with that over the Elbe.

Bridges of Germany.

Bridge over the Elbe, at Dresden, was restored from 1727 to 1731, by Poepelmann, in the reign of Augustus, Elector of Saxony and King of Poland. The ancient piers, which are the work of the twelfth and thirteenth centuries, and which were paid for by indulgences, are the nuclei of the present. Originally there were twenty-four, but several were carried away at different times, and when the fortifications of Dresden were extended to the Elbe, some were destroyed. The bridge is now composed of eighteen arches, distributed without order, nor can this be a matter of surprise when it is considered how they were constructed. The total length is 1447 feet, the breadth of the road is 25 feet, and that of the footway 4 feet 7 inches. Notwithstanding all its irregularities, it is one of the longest in Europe, that of St. Esprit and another at Prague only surpassing it, and it may be regarded as one of the finest. The piers are very thick, being in some instances nearly equal to the span of the arches, which vary from 40 to 62 feet. They rise to the level of the footway, and serve as recesses for benches. On one is placed a bronze figure of Christ on the cross, richly gilt; the parapet consists of an iron railing, strengthened over each pier by pedestals, which sustain vases.

The roadway is nearly level, and forms a superb promenade. The bridge is entirely constructed of squared stones, and the voussoirs are rusticated.

Bridge at Prague, on the Moldaw, was commenced in 1638, by Charles IV., Emperor and King of Bohemia, who laid the first stone, and finished under Charles VI. Its length, 1706 feet, is greater than that at Dresden, but it does not equal it in its construction. The breadth is 35 feet 8 inches. The eighteen semicircular arches of which it is composed are constructed of squared stone, and ornamented with an archivolt: the piers are surmounted by pedestals, which support statues; that of *St. John Promucena* is placed over the very spot where King Venceslas threw him into the river, for refusing to violate the secret of confession. The masonry of this bridge is excellent: when the Swedes seized upon Prague,

and were desirous of destroying it, they found the mortar so hard, that they were obliged to give up the undertaking.

Bridge at Ratisbon, over the Danube, began in 1135, by Henry the Superb, Duke of Bavaria, consists of fifteen arches, and its total length is 994 feet. The piers rest on piles, and are defended by jetties and large starlings. It is only 21 feet 4 inches wide; it is paved with square stone; the footways are only 1 foot in width, and the parapets are formed of flag-stones, placed on edge, united by iron cramps, and run with lead. At about one-third of the length there is a descent upon an island, by means of a staircase contained between two walls.

The arches are semicircular, and are from 33 feet to 53 feet span.

Bridge of *Zwettau*, over the Torgau, on the Elbe, was built by King Augustus, in 1730. It consists of twelve arches; of the eleven piers five have starlings; the others have only a set-off. The fall of this bridge is very considerable.

Bridge at Wurtzbourg, over the Meine, consists of eight semicircular arches, 32 feet 9 inches span; the starlings of the piers are semicircular, and rise to the level of the parapet; the work is simple, and very solidly constructed. Statues are placed on the piers, and among them is that of St. John Promucena, regarded in all Germany as a patron of bridges.

Bridge of Kosen, on the Saal, near Naumbourg, presumed to have been constructed in the tenth or twelfth century, consists of eight arches; the five in the middle of the current are pointed, the others are semicircular.

Bridge of Mossen on the Mulde, in Saxe, is composed of three semicircular arches; was constructed from 1715 to 1718, by Daniel Poepelmann, under the reign of Augustus.

Bridge at Nurembourg, called A B C over the Pregnitz, built under the Emperor Charles VI., who laid the first stone, was finished in 1728; it is formed of two arches 46 feet span. In the interior of the pier is a vaulted passage; this pier is surmounted by two obelisks, erected to the honour of the emperor; the parapets are ornamented with pedestals surmounted by a ball.

Bridge of the Boucherie, at Nurembourg, over the Pregnitz, constructed in 1599 by Peter Carlo, presented many difficulties in its foundations; it consists of a single segmental arch, 97 feet 2 inches span, and 12 feet 9 inches high; the thickness of the arch is only 4 feet, the breadth of the bridge is 40 feet.

CHAP. VI.

ENGINEERING IN FRANCE.

We have seen that wherever Imperial Rome extended her sway, she has left memorials of those useful works which have rendered her name immortal among the nations, and it is not too much to conclude, that after the long night of barbarism which succeeded the overthrow of her mighty power, when civilisation again dawned, they would be the guide for whatever improvements might be required, and we have sufficient evidence that they were the models from which the after inhabitants derived the knowledge they possessed on the subject; but we can hardly say that the engineer was fully called into practice earlier than the middle of the seventeenth century, about which period Bernard Forrest de Belidor wrote his "Architecture hydraulique," which awakened great attention, and laid the foundation for those theoretical studies, which had been entirely neglected by practical men throughout Europe. This writer, an officer in the artillery, was requested to suggest some system to guide the military engineer; which eventually led to the establishment in the year 1720, of the Ponts et Chaussées, first composed of an inspector-general, or chief architectural engineer, three other inspectors, and twenty-one assistant engineers. The number was afterwards increased to twenty-five and twenty-eight, and in the year 1770, fifty inspectors were added, taken from the sub-engineers, the numbers of which depended upon the necessities of the service. This important and erudite body, acquainted both with theory and practice, directs the education of all who intend to act as civil engineers, or undertake the construction of roads and bridges; and they require those who aspire to the superintendence of these works to possess a knowledge in geometry, mechanics, mineralogy, and the natural properties of all the materials employed in the arts of construction.

Among the engineers of this institution are registered the names of the most celebrated mathematicians of France, who have contributed to the formation of a theory upon whatever subject they may have been employed. Such an establishment for carrying out the

national improvements could not fail of being successful: each enterprise submitted to the board is duly and properly considered, with reference to works, that might be in future undertaken; one uniform system is laid down for bridges and their construction, and volumes have been written on the properties of stone, cements, hydraulic mortars, the thrust and pressure of arches of every kind of curvature. Timber has been examined thoroughly with respect to its strength, toughness, and powers of resisting, torsion, and much larger scantling than ever tried in this country, have been tested by the engineers of France. The best works upon engineering are found among the writers of France and Italy, and should be studied by all who desire to excel in the profession. Rondelet, Bruyere, Prony, Boistard, Berard, Gauthey, and Perronet, particularly should be enumerated for their high attainments and professed knowledge of the subjects upon which they treat. Before the establishment of this important body, the roads in France were scarcely defined, and the bridges were left to the control and management of the local masons, who executed their repairs or reconstruction in a manner devoid of both proportion and solidity.

Under the Emperor Napoleon, great advances were made in the management of all public works; his penetrating eye soon discovered what was wanting, and his industrious and business-like habits changed the routine observed in the building of bridges, the formation of roads, construction of lighthouses, beacons, telegraphs, arsenals, canals, working of mines, and the reducing of metals.

France is divided into eighteen districts, and placed under the inspection of this establishment.

The roads are classed or divided into three orders, as the Royal road, for which the state provides, the departmental roads, which are kept in repair by the respective provinces, and the rural roads, which are maintained by the immediate inhabitants of the district through which they pass.

The Royal roads are subdivided into three classes, the first of which is 42 French feet in width: of this class there are 28, or altogether 1258 leagues; of the second class, which are 66 feet in width, there are 717 leagues; of the third class there are 5241 leagues.

The rivers, as far as used for the purposes of navigation, are under the same direction, and 1877 leagues are annually reported upon.

The canals finished extend over 370 leagues, and those under construction amount altogether to near 2000 leagues, and constitute another branch to which the engineers of this government board have to attend; and that due attention may be paid to this highly important subject, the duties are divided into lines, and are annually reported upon.

The first line passes by the south and east of France, comprising the Rhone, the Saone, and the Canal of Monsieur, which unites the latter river with the Rhone.

The second line passes by the south and north of France, and comprises all that is attached to the Rhone and Saone in that quarter; the canal of Bourgoyne, which unites the Saone to the Yonne; the Seine; the Oise; the canal of Manecamp and Chauny; the Canal Crozat; the canal of St. Quintin, joining the Oise to the Escaut; the canal of the Somme or of the Duke d'Angoulême; the course of the Escourt; and all the canals in the neighbourhood of Calais.

The third line, in the centre, on the south, comprises the Rhone, the Canal Lateral, course of the Saone, Canal du Centre, of Dijon, Chalons on the Saone, which unite the Loire with the Saone; Canal de Berri; of Dijon; and Bec d'Allier; the canal which joins the Loire from Bec d'Allier to Briare; the Canal Briare and the Loing; the course of the Seine and Oise.

The fourth line, passing by the south and north-west, comprises the Rhone, the Saone, the Canal of Burgundy, the Yonne, and the Seine, to the mouth.

The fifth line, passing from the south to west, through the centre of France, has the Rhone, the course of the Saone, the Canal of the Centre, the canal de Berri, the branch canal to the Basse Loire, from Tours to Nantes, and the canal of Nantes to Brest.

The sixth line, passing by the south and south-west, has the canal of Marseilles, to the port of Bouc by the Lake de Berre; the canal de Bouc to Arles; the branch canal to the Rhone, from Arles to Tarascon; the canal de Beaucaire, the canal de la Radelle, the canal of Mauguio and des Etangs, the canal of Languedoc, and its extension to Moissac by Montaubon; the Garonne from Moissac to Bordeaux.

Seventh line, passing from La Manche to the sea, by Gascoigny and the Mediterranean, or the canal from Dunkerque to Bayonne and Marseilles; the canal de Bourbourg, the navigation of the Aa; the canal of Aire to Bassée, joining the Lys, to the H. Deule; the canal of Deule; part of the course of the Scarpi; canal of Sensée; the course of the Escaut; the canal of St. Quentin; the canal of Crozat; the course of the Oise; canal of the Oise to the Seine; canal of St. Denis and St. Martin; the Seine as far as the canal of Loing; canals of Loing and Orleans; the Loire from Orleans to the mouth of the Vienne; the Vienne to Chatellerault; the canal of Poitou, joining the Vienne to the Charente, by the Clain river; the Charente to Angoulême; the canal from Angoulême to Libourne; the Dor-

dogne from Libourne to Cubzac; the canal of Cubzac to Bourdeaux; the Garonne to the mouth of the Bayse. When this line is prolonged, it will take a course towards the west, following the canal of Landes, and the river Adour to Bayonne; and towards the east it will comprise first the course of the Garonne to Moissac, the canal of Moissac to Toulouse, by Montauban, the canals of Languedoc, des Etang, Mauguio, La Radelle, Beaucaire, from Tarascon to Arles, from Arles to Boue, and from thence to Marseilles.

Among the ports of France, that of Dunkerque, before its demolition in the year 1714, was the great school for engineers, and presented more examples for study than any other in Europe; here was found an assemblage of every kind of hydraulic architecture, of which single or detached specimens existed elsewhere.

Julius Cæsar found it a mere village inhabited by fishermen, attracted thither by the excellence of its natural harbour; the neighbouring country, mostly under water, was supposed at one time to have been an arm of the sea, which extended to St. Omer, anchors and parts of vessels having been found there whilst constructing the fortifications. The land around has been rendered serviceable to agriculture by the cutting of several canals, to drain off the waters, and carry them into the sea. The opinion that the sea has retired is, perhaps, not correct, for the level of the water is above that of the neighbouring plains, which would be subject to inundation but for the formation of the dunes or banks of sand, which serve the purpose of an embankment. The shore along the entire coast is composed of sand, which the slightest wind drives in the direction from north to south, depositing it in irregular ridges, which sometimes rise to small hillocks; these the early inhabitants rendered more compact by mixing with them layers of bushes, branches of trees, yellow broom, or any other material which occasioned the sand to bind; in process of time a barrier was formed, which resisted further encroachments from the sea. At several places the sluices, introduced for letting off the fresh water, were closed, when the sea again flowed in by constant manual attention. The name this port bears arose from the circumstance of St. Ely, Bishop of Meyon, in the seventh century, founding a church on these downs, which was called Dunekerque in the Teutonic language.

In the year 863, Charles le Chauve bestowed the town and the country around upon his son-in-law, Baldwin, who was created Count of Flanders.

Baldwin III., his great-grandson, surrounded the town, which had obtained by that time some importance, with a strong wall: as a port it was afterwards much frequented, in consequence of its abundant supply of fresh water, which fed the canals, and formed its most important defence. In the twelfth century, it acquired the dignity of a maritime port, and contained several vessels of war, some of which were adapted for long voyages. Various improvements successively followed, and Dunkerque in the course of a few centuries became a highly important station; in the year 1677, the great Vauban was desired by Louis XIV. to construct a channel between two jetties, at the head of which were established the two forts, *Verd* and *Bonne Esperance*, also the famous Risban on one side, and the Chateau Gaillart. These great works were completed in 1683; and two years afterwards, the basin was lined with a stone wall, and the quays formed. At its entrance a grand sea lock, 42 feet in width, which allowed vessels of considerable burthen to float within the harbour was constructed. The fort of Revers was built in 1689, and several contrivances were adopted, which, aided by the waters of the two canals, deepened the port, and kept it clean and scoured. M. Clément, who directed these latter operations, became one of the most eminent civil engineers in Europe. In the year 1701, a new risban, called the Fort Blanc, was erected at a distance of 800 toises from the town.

Chateaux Verd and *Bonne Esperance* were situated, the first on the east, the second on the west on entering the port, at a distance from the town of about 1000 toises. They were formed of timber, raised on piles, rendered extremely solid, and each mounted with thirty pieces of cannon. Passing between the two jetties which formed the channel, which was 40 toises in width, on the west, stood the celebrated fort called Risban, constructed of stone, and containing commodious barracks, a cistern, magazines, and other requisites for a garrison. It communicated with the town by means of a jetty. On the rampart were forty-six cannon, which could be placed on three sides; the form of the fort being that of a triangle. To the east was a smaller, called the Petit Risban or Fort Blanc, also of masonry, which had twenty pieces of cannon.

Towards the harbour, on the same side, stood the Chateau Gaillard, a timber construction, and communicating with the eastern jetty by a small bridge. The form was rectangular, and contained twelve pieces of cannon; one side defended the jetty, and the other crossed the range of Fort Blanc; on the other side of the channel was the battery of Revers, built of masonry, which had sixteen pieces of cannon.

The jetties, formed of timber and large stones laid on carefully at a vast cost, were the admiration of all engineers. The basin contained forty lines-of-battle ships afloat at the time of low water; the entrance lock was 42 feet in width, and the whole was surrounded by arsenals and storehouses for the marine.

The harbour was supplied with every means for cleansing and deepening; its chief sluice

for this purpose was at the end of the canal of Bergues, in width 26 feet, with a double pair of gates (*Portes Busquées*); one of these supported the waters of the canal, the other that of the sea at high water, so that vessels could pass from the canal to the port, and from the port to the canal at certain times of the tide; this arrangement was one of the earliest of its kind. The sluice had others attached to it, which turned when the sea was low and the harbour dry, to allow the waters which served as a reservoir in the canals to flow out with so much violence and velocity that they thoroughly scoured the harbour and the channel between the jetties; its effects were felt to the extent of 1600 toises, the distance of the sluice from the head of the jetties. At the mouth of the canal of La Moere, a sluice of a different construction was established, which served a similar purpose; when they acted singly or together, they produced a force which perfectly answered the desired purpose.

A third sluice at the canal of Furnes, within the town, contributed to clear the channel, and from 1701 to 1710, the port was cleaned and scoured out to the depth of 15 feet by these contrivances.

The grand sluice to the basin at Dunkerque, constructed by Marshal Vauban, in the year 1684, was considered throughout Europe the masterpiece of its kind. Its width was 42 feet, and the gates supported a weight of water, 20 feet in height.

The foundations were laid on a moving sand, into which were driven eight rows of piles; these carried as many pair of binding pieces, through or between which were driven a double row of sheet piles, care being taken that those of one row covered the joints of the other. Between the heads of the piles was laid a foundation of brick, carried up with mortar made of Dutch tarras, and the whole was brought up 18 inches in height, and made level with the tops of the binding pieces; other piles were driven under the walls. Between the first and second row of sheet piles were laid ten cross timbers; between the second and third, fifteen; between the third and fourth, two; between the fourth and fifth, six; between the fifth and sixth, two; between the sixth and seventh, eleven; and between the seventh and eighth rows, ten; these cross timbers extended throughout the whole width of the foundations that were to be occupied by the sluice. Between these timbers the spaces were filled in with masonry, and the whole brought to a level; a floor of oak plank was then laid over, dowelled, pinned, and securely caulked at the joints.

On this floor was a second row of cross timbers immediately over those below, excepting in that part occupied by the four principal pieces which came under the base of the framing of the pointing sills, which were 54 feet in length, entering at each end 3 feet into the walls, and their scantling was 24 inches square, or a double thickness. Forty-three longitudinal timbers at right angles with the two rows of transverse timbers were now halved down, and securely pinned. On these were laid a third range of transverse timber, which formed a second grillage, and after the intervals were filled up with masonry, a second floor of planking was laid over the whole, and pinned and caulked down as the other. The quantity of timber employed in this construction seems, however, to have been more than was necessary.

The masonry of the side walls was then carried up, leaving in each a small aqueduct, arched with stone; they were 3 feet in width internally, and lined throughout with hard and durable stone, to resist the violence of the water; these were the more necessary as the gates, which were curved, had no small sluices for the passage of the water.

The counterforts were made equal to sustain any pressure to which the side walls might be subjected; and two others were placed to receive the iron ties that secured the collars of the gates. The aqueducts were closed by paddles, 3 feet 6 inches wide, each of which sustained a considerable pressure.

In the construction of the side walls, four iron uprights were introduced 6 feet below the top, at the groove where the paddles worked, two being placed on each side, and the whole four at an equal distance, occupying a square of 3 feet each way. Each of these iron uprights had at the lower end an eye, with an iron key passed through it, 8 feet in length and 3 inches square; these were attached to iron anchors, 7 feet in length and 3 inches square, the whole for the purpose of rendering it solid. On the top of the masonry were four solid blocks of timber, 18 inches square; on these was placed the box with a groove in which was the nut of the screw. The nut was turned by means of levers, and the screw mounted, which carried with it the paddle below.

The Sluice at the Mouth of the Canal of Bourbourg, used for scouring the harbour of Dunkerque, had a clear width of 14 feet, and the side walls were sufficient in length to allow of two sea and two land gates, with a swing bridge between.

After the several rows of piles which carried the binding pieces that confined the sheet piling were driven, the cross timbers were placed under the sills, their extremities being allowed to pass through the side walls. On a series of longitudinal timbers was laid a course of transverse ones; after the intervals were closely filled with masonry, there was laid a floor of plank. Above this, and immediately over the first transverse timbers, was another, which was doubly floored; the upper planks crossing the lower at right angles.

Between the rows of piles, and particularly in the front towards the sea, was a filling-in of clay.

The turning gate revolved upon a pivot, at the end of a middle post; on each side of this post, and framed into it, were five braces; over the skeleton framing towards the side on which the water was retained, it was closely boarded; and had two openings which were shut by paddles, worked by a rack and pinion. The top of the middle post had a collar, through which it passed, and in which it could turn freely round. This turning gate was made two feet more in width than the lock, and shut against a reveal on each side in the side walls, constructed for the purpose. To keep this gate firmly closed, a wedge-shaped piece of timber work was pressed against it, which was moved by means of a rope attached at the top. When it was required to open the turning gate, the small paddle was first removed, and as the water escaped, the gate was gradually slacked by a cable attached to a capstan. The tide as it mounted shut the gate again, by mere pressure; the lock-keeper dropped the wedge and closed the paddle, when the water required was admitted.

Sluice of the Canal of Bergues is a good exemplification of the manner in which M. Clement laid the timber foundations, where the soil, as in this case, was a moving sand.

The outline of the platform being set out, piles were driven, from 10 to 12 feet in length and about 11 inches square.

Four double rows of piles were driven to carry the binding pieces, morticed at the head of the sheet piling, driven in at the two extremities of the platform; others were placed under the sills, and a single row at the angles, made by the side and cross walls; the planking was laid against, and not morticed, as in other instances, into these binding pieces. These ten rows of double and single piles were capped by as many binding pieces; the piles were driven at every six feet, and so dispersed, that in the double rows, one came opposite the intervals of the others. The binding pieces, placed four inches apart, formed a groove or space regulated by the thickness of the planks introduced between them, which were by this means kept in a line. These were also guided at the foot by another fixed piece of timber, which prevented their being driven out of place; these pieces were secured at regular distances by round pins passed through holes made at every six feet, and were kept in their places by keys passing through their ends. When a sheet pile came in contact with one of these pins, it was taken out, and a hole cut to allow it to pass; when the sheet pile was again driven, other square pins were substituted, passing through the sheet pile and its two binding pieces, the rows of which extended throughout the entire width of the foundation, and three or four feet beyond the projection of the buttresses, to prevent the current of water from entering the foundation, which is the main use of sheet piling. Several divisions are necessary in structures of this kind to ensure perfect success.

With respect to the other piles, as many rows were driven as there were cross timbers; viz. three between the first and second rows of sheet piling, six between the second and third, five between the third and fourth, six between the fourth and fifth, and three between the fifth and sixth, these rows being three feet apart from centre to centre. The number of piles in each row was encreased according to the nature of the bottom, but they were more frequent under the wing walls than under the platform, where there were scarcely any, except under the timbers which run lengthwise; sometimes they were omitted, whilst under the wings and piers, where the lock had several passages through heavy masses of masonry, more precautions were taken, and a greater number of piles driven, they having the effect of bearing the additional weight, and also serving to consolidate the soil, which is compressed in a ratio proportionate, inversely, to the reduction of the volume of earth. After the piles were driven, they were cut off about 3 feet 6 inches above the bottom where the filling in masonry commenced; their heads were levelled, except those to which were attached the binding pieces, which confined the sheet piling. The head of each pile had a tenon cut on it, which passed through the mortices of the cross timbers, formed a capping, and were held fast by an iron pin passing through them. The longitudinal and cross timbers were about 30 feet in length, and 12 inches square. When all the piles were driven and the loose earth taken out between the heads, the spaces were filled with good masonry to the depth of about three feet, after which the cross timbers were laid, the under parts of which were filled with mortar and closely bedded. The cross timbers which came under the two sills, as well as the masonry, were raised a foot higher above the piles than the others, to form that part of the chamber of the sluice against which the gates rested.

The cross timbers being placed, they formed the first layer, which entered partly into the masonry; above these was another platform of longitudinal timbers, crossing the others at right angles, and being halved in and well secured at the intersections by irons.

One line of longitudinal timbers was laid under the face of each wall, both back and front; the others in the intermediate spaces, so that there were four under each wall. The platform between the walls was divided into four equal parts, and at each division was laid a longitudinal timber, and some short lengths under the counterforts.

When the double layer of timber was completed, the voids were filled up with masonry;

when brought to a level, a bed of mortar was spread over the whole; and on this, in the space comprised between the chamber walls, was a floor of three-inch oak plank, secured down upon the cross timbers, for the purpose of preventing the springs from working upwards. Under the walls it was omitted, that the masonry might unite more firmly with the foundations.

The floor was again crossed by other timbers placed directly over those below, and halved on the five longitudinal pieces forming a third layer, or grille, which extended only over the chamber; these were pinned down with iron; when these timbers were laid, others, which formed the sills to the chief parts of the lock, were placed.

The intervals of this timber platform were then filled up with masonry, and levelled as before. A floor of three-inch oak plank was pinned down to the chief timbers; over this, in a contrary direction, was another floor two inches thick, a fall being preserved of one in forty-eight in the direction of its length, to allow the water to run off when repairs were required.

After six lines of sheet piles had been driven in different directions, the Maréchal Vauban added a double row at the pointing sills, which, with the other parts of the construction, were then commenced.

The side walls and their counterforts were set out, and the various courses of facing were all cramped and worked with care; a backing of clay, 5 or 6 feet in thickness, was rammed down as low as the first course of masonry, and brought up to the level of high water.

Sluice of the Canal of Bergues, which was used for the purpose of deepening the port of Dunkerque. It consisted of two gates, one contrived to hang within the other; the lesser opened seawards, and the whole turned so as to admit boats into the canal. The outer gate, being scarcely anything more than a margin to the first, carried a triangular piece of framing, which was requisite in order to render the inner gate secure; this is called a *port busquées*, and is more curious than useful. At low water the triangular frame was unhooked from the great gate, and the lesser one being relieved, opened suddenly and allowed the water to pass through with violence, pushing any obstructions before it. At high water the small gate was again closed, and the triangular piece of framing called a valet was hooked to the outer frame, and effectually prevented its opening.

A turning gate in the canal of Bergues, as designed and executed by M. Clément, in the year 1705, is an excellent example. The width of the lock was 27 feet 6 inches, so that each gate was in width half that dimension. The ports were 15 by 17 inches, as were the horizontal rails: these together formed the skeleton framing, in which revolved the turning gate, 13 feet 6 inches in width, and 10 feet in height. Where the rails entered the uprights, they were secured on both sides by strong irons. The upper horizontal rail was 15 by 13, and the braces 11 by 9.

The gate was supported when closed in a reveal on each side, and turned upon its centre; when this was required, it was only necessary to raise one of the paddles, and to keep the other closed, for as the water was allowed to pass through one opening freely, the closed one receiving the entire weight, was on that side more pressed, and consequently impelled forward by the weight of water against it. Both sides were then closed, and the force, being equal over each half, prevented it from turning either way.

Sluice at the Mouth of the Canal of the Moère, about 15 feet in width, was not contrived for the purposes of navigation. It had one pair of gates and a sluice gate, raised by a wheel and capstan, or a wheel termed hérisson, formed by a number of handspikes. The gates were opened at low tide, and after the water had left the canal, the sluice gate was raised to a height sufficient to allow the proper quantity of water to pass, and the force with which it ran out effectually scoured the mouth. The sea again entered the canal, where it was confined by shutting the gates, when the sluice was afterwards lowered; at the time of low water it was let out, and the operation continued as long as it was deemed necessary for scouring purposes.

The vanne of the canal of Moère was about 16 feet in width, and 13 or 14 feet of water usually pressed against it; its thickness was about 8 inches, and it was firmly secured by eight bands of solid iron. To raise it, a species of tread-wheel, upwards of 29 feet in diameter, was placed on each side, worked by men; to the axle that turned round, ropes were attached, and by the aid of blocks and pulleys, the vanne or gate was lifted to the height required.

The channel of the port of Dunkerque was at first bounded by jetties constructed with fascines, which were laid in the year 1679, at the time Louis XIV. became possessed of the port.

It being found necessary that the sluices should operate more powerfully, and deepen the channel, the jetties were carried out to a greater distance. Jetties formed with fascines are admirably adapted to receive the surf, but require a constant outlay to maintain them, and should therefore only be used as a temporary expedient, or to facilitate the arrangements of more solid constructions, for which purpose, when properly formed, they are exceedingly useful. The breadth given to the base was three times that of the height, which here was

25 feet 6 inches. To limit the width of the foundation, two lines were set out not quite parallel, because the depth increasing as they proceeded, rendered it necessary to increase the width, at the same time that of the channel was made equal throughout, the difference being given to the exterior face of the jetty. Some of the earth being removed, the first bed of fascines was laid, and to prevent the sea from undermining the work, a trench was dug and filled in with well-rammed clay; fascines united in masses were covered with heaps of clay, which filled up the inequalities and holes in the shore, before the work was brought to a level.

When the necessary trenches were cut, several layers of fascines were laid within them 6 or 7 feet in length, and from 18 to 20 inches in circumference; when laid across the intended jetty they formed a bed of about 12 inches in thickness. The ends of each layer were dressed to the form required by the slope; small stakes 3 feet in length were driven through them at the distance of 18 inches, and rows were so formed at every 3 feet. Rods 15 to 16 feet in length were then worked round the heads of the stakes, and the whole securely wattled together.

The beds of fascines were repeated in a similar manner, until the whole mass was brought up to the height required, care being taken that the rows of stakes were placed in various places to unite the upper layer with that below it. This work was only carried on after the tide had retired, and it was found necessary to load it with large stones, to avoid any movement that might take place from the rolling in of the sea.

The entire surface was covered with a grillage of fir timber, 4 or 5 inches square, leaving compartments of 2 feet square. Piles were required to maintain them in their position, one being driven slantways in each mesh of the square, they were from 12 to 13 feet in length, and 12 inches in circumference at top, gradually diminishing towards the point; a hole was bored at the head, through which a stake about 18 inches in length was passed, to retain the timber grillage, and prevent its moving. The squares were filled with stone, laid dry, placed on edge, and well rammed with wooden rammers, that the stone might not fracture. The crevices were filled with smaller pieces of stone, or the chippings from the quarry.

The whole of the work was protected by piles, to prevent any injury from the passage of the vessels to and from the harbour, and these also served to support a small continued line of bridges that communicated with the forts. The slopes and top being completed with fascines, a series of framing was laid throughout, at distances of 9 feet, similar to those used in the construction of quays. Each frame being formed of a protecting pile from 36 to 40 feet in length, 16 or 17 inches square at top, and capped with timber about 12 inches by 8, so as to unite the whole line together. These piles were retained in their position by tyes, which ran through the entire width of the jetty; each bay was strengthened in various directions by cross timbers, 12 inches square.

The jetties so constructed of fascines did not continue more than twenty years, when it was found necessary to construct them more solidly, and Maréchal Vauban approving of the plans suggested by M. Clément, he was directed to form them of timber and stone.

The old fascines were removed to within 3 feet of high water mark; those below had become so consolidated by the deposit of sand and other matter, as to be rendered strong enough to support the weight intended to be put upon them. Lines were drawn at every 20 feet, and piles driven at about 2 feet 9 inches apart, which were cut off at a uniform height, leaving a tenon to mortice into the longitudinal timbers placed over them. Rows of piles were driven between these lines, and these were repeated at every 8 feet, the width of each bay. On these rested the sill of the framing, halved on to the longitudinal timbers, and morticed to the heads of the five intermediate piles, on which was constructed the framing.

The piles were 9 or 10 inches square, and the long timbers which capped them 13 or 14 inches square, 25 feet long, and their scarfing joints 3 feet long. The transverse timbers which formed the sill of the frames were 25 feet in length, and 13 inches square; their ends were dovetailed into the longitudinal timber to the depth of three inches. The middle horizontal timber was 13 inches square, and the upper one 12 inches square; these were dovetailed into the side timbers which formed the slopes.

The St. Andrew's crosses were formed of timber, 9 inches square, morticed and tenoned at the ends. The struts were 9 inches square, dovetailed at the ends, and the upright post was of the same scantling.

The slant parts of the exterior were 12 inches square. The binding pieces the same scantling, and 25 feet in length. The whole was planked throughout, and capped at the top.

After the framing was complete, it was filled in with hard stone, laid carefully by hand and without mortar, fine gravel being substituted.

The celebrated Risban or fort, which was constructed in masonry to guard the entrance of the port of Dunkerque, was distant 550 toises from the bastion, and 50 from the mouth of the canal: the length of each of its three sides was fifty toises, and it rose 46 feet above the

level of low water. Eighteen embrasures were formed for cannon, and so arranged, that sixteen could be brought to bear upon vessels in the roadstead: on the other side it commanded all the approaches to the citadel.

The lower floor, which was entirely below the ground, served as a deposit for stores; the upper for the use of the garrison, above which was the magazine for powder. On the first floor was a chapel, and on the second a room for the deposit of biscuit.

Over the roof was contrived a lighthouse or beacon, 8 feet in diameter, with a small dome covered with lead.

On one side of the fort was the lodging for the commandant, consisting of kitchen, dining-room, and two chambers, with all the necessary offices, from which was a ready communication with the whole of the ramparts. On the opposite side was a lodging for six artillery men, a covered shed for the cannon, and the magazine, in which ammunition was kept: adjoining these were the barracks, consisting of twelve rooms capable of accommodating an hundred men. Three staircases conducted to the several parts of the ramparts, and the whole was well provided with water, which was kept in two large cisterns, placed opposite the governor's house.

Vauban executed this work without a coffer-dam, at the time of low water, the tide rising about 13 feet. Piles were first driven round the site to be built upon, and four-inch plank in six feet lengths secured to them, and further kept in their places by binding pieces on each side. These were surrounded by sheet piles.

The Canal of Mardick, cut after the demolition of the fortifications at Dunkerque, to discharge the superfluous waters, was completed in the year 1715, under M. Le Blanc; and the lock he constructed was considered the finest in Europe. It was divided into two passages, one 47 feet in width, the other 27 feet; its length was 295 feet; that of the middle wall 32 feet, and each of the side walls without the buttress, 25 feet. It was distant from the sea 3384 toises: the width of the canal was 50 toises, and its depth 21 feet.

The turning gates employed at this sluice were remarkable for some ingenious contrivances: in particular, that placed in the widest passage; that in the smaller resembled one already described in the lock at Bergues.

When required to be closed, one paddle was lowered, and the other raised: each opening being made a little more than 6 feet square. The weight on the fresh water side being greater than that towards the sea, it was necessary to provide an additional contrivance to keep the turning gate secure in the reveals against which it lodged. For this purpose, two locking bars, moved by a perpendicular rod, were introduced; a simple jack at top elevated the rod to which the latches or locking bars were attached, and which being raised relieved the gates.

To raise the paddles, the lock-keeper descended by a ladder, placed on the land side, against the gate, and by means of a rack and pinion lifted it up; the other paddle being previously lowered, that the sea might close the gate on that side when the canal had received the quantity of water required. Capstans and cables were attached to the lower half of the gate, and facilitated both its opening and shutting. A chain secured to each side by means of rings prevented the gate from closing, and supported it against the violence of the water as it rushed through.

Gravelines is situated on the river Aa, which runs through a fertile portion of Artois, and empties itself into the sea, amidst the sands and dams thrown up on the coast, which being at this point extremely flat, there was a constant accumulation of stagnant water in the ditches, for which it was difficult to obtain any outlet. Gravelines became the tomb of all the garrisons sent there.

At the commencement of the seventeenth century, Philip III., King of Spain, turned his attention to its improvement, and constructed a canal near Gravelines to carry off the water by a shorter course; and at about 900 toises from the counterscarp, where high water flowed, a large sluice with a double pair of gates was formed: this was soon afterwards destroyed by order of Cardinal Richelieu.

In 1659 it was ceded to the French, and in 1737 Maréchal Vauban commenced improving the drainage of the district. He formed a new lock, divided by a wall of masonry into two unequal passages, intended to aid the discharge of the waters of the river at the time of land floods. Its length was 105 feet, and its width 100 feet. Coffer-dams were made use of, and after the earth was taken out to a sufficient depth, piles 8 or 9 feet in length, and 12 inches square, were driven entirely over the whole site; others were added to the side and middle walls, altogether amounting to nearly a thousand, all placed in parallel lines, morticed and tenoned into the longitudinal and cross sleepers above.

After these and the necessary rows of sheet piling were driven in, the ground was levelled, and the earth taken out to the depth of 30 inches; the spaces were then filled with masonry. In this was laid the lower grillage or timber platform, composed of twelve longitudinal timbers 12 inches square, so placed that they lay under each side wall, the same number under the middle wall, one in the narrow passage, and two in the other. These were secured to the heads of the piles by pins 12 inches in length and 1 inch square. Upon

this was laid a second platform of timber of the same scantling, crossing the first, and securely pinned to it by barbed irons, 14 inches long and 1 inch square. These cross timbers were placed 21 inches apart, and the spaces filled up with brick laid in tarras, or mortar made of lime and sand, with a proportion of one third of Dutch tarras. An oak floor, 3 inches thick, was laid over the spaces between the intended walls, formed of planks, none of which were less than 20 feet in length, fastened by spikes, 7 or 8 inches in length, as well as wooden pins; after which the joints were caulked. In the passages was a range of longitudinal timbers, and three others under each of the three walls, care being taken that one of these should be under the face of each wall: these longitudinal pieces were secured to the cross timbers below them by barbed iron pins, 17 to 18 inches long, and $1\frac{1}{4}$ inches square. Upon this third platform was another course of cross timbers, each in one length, placed immediately over those below: their length was only 4 feet more than the width of the passages. These cross timbers were united to the longitudinal ones below by similar iron pins to those described, 18 inches in length. The spaces between were filled up with brickwork to the level of the top, on which was laid a coat of mortar and a layer of moss, over which was another floor of plank, 2 inches in thickness, but not extending beyond the water-way.

As this work advanced, the main timbers for the pointing sills were laid down, and the two ends of the platform were secured by rows of sheet piling confined at the head by binding pieces 12 inches square. The chief timbers under the pointing sills were 28 feet 6 inches long, and nearly 2 feet square. Those of the smaller passage were of the same scantling, but less in length.

The sill which sustained the heel parts of the great gates was 28 feet long and 2 feet square. The pointing sills were 10 feet long and 24 inches square, all secured by iron pins.

The sill of the smaller passage was 23 feet long, and 2 feet by 1 foot 9 inches square; that of the turning gate was 25 feet 6 inches in length, and 2 feet square: to give it additional strength, two timbers of the same scantling were laid at right angles with it in the middle of the water way. After the whole was carefully set out, and the site for the walls traced, the masonry was commenced with stone from Landretun, which was laid in regular courses 10 inches in height, and having their beds not less than 20 inches. These stones were cramped wherever there was any pressure, particularly where the turning gate was placed, and the reveal carried up to receive it. The walls were backed with brickwork laid in cement, to the thickness of from 2 to 3 feet, above which common mortar was used. The bricks were dipped in water previous to being laid.

The side and middle wall being carried up 4 feet above the level of the highest floods were finished by a course of flat stones.

The turning gate was composed of two upright posts besides the middle, which had the pivot on which it turned. There was a bottom, a top rail, and two horizontal between, which were braced from the middle post; and at each mortice and tenon the joints were secured by strong irons. The middle or turning post, 17 feet in height, and 18 inches by 16 inches square, worked its gudgeon in a collar. The outer posts were 12 feet 9 inches in height, 13 inches by 11 inches. The gate was 1 foot more in width than the water way, that it might rest securely agrinst the reveals prepared to receive it when closed.

One side of the turning gate was wider than the other, that the sea, at the time of flood, should have the power of shutting it: it was not quite at right angles, but presented an inclined face to the action of the water. A valet was contrived on the inside to keep the gate closed, and prevent the fresh water from running out of the canal at the time of low water. This valet or key to secure the gate was formed of a turning point, 11 feet in length, and 12 by 7 inches, and a branch 15 feet in length of the same scantling, united by two ties framed into it and rendered secure by iron straps; when used, a rope or chain was attached to the upper hook, which pulled it round on its pivot, and when brought flat against the turning gate, it was secured to the middle post, and prevented the water from the sea-side from forcing it open.

The Port of Cherbourg, in the department of La Manche, in 49° 38′ north latitude, and 1° 37′ west longitude; it is situated on the most northern coast of the peninsula of Contentin in Normandy, and the bay between Cape de la Hogue and Barfleur, and has the form of a crescent. There are two harbours which communicate by means of gates, and at the entrance two piers have been carried out; that on the east side extends nearly half a mile in length, and the other about half that distance, the width at the entrance being 210 feet. The outer harbour is in length 360 yards, in width 250, and has a depth of water at low spring tides of 30 feet.

The quay, 200 feet in width, is built of stone, and extends in a straight line from Fort du Hamet to Fort du Gallet: the inner basin is entered between two circular returns.

Napoleon expended vast sums of money in the construction of docks, slips, and quays, using the granite obtained from Barfleur.

This port is cleansed by sluicing, at the time the tide is low, or when there is not more than

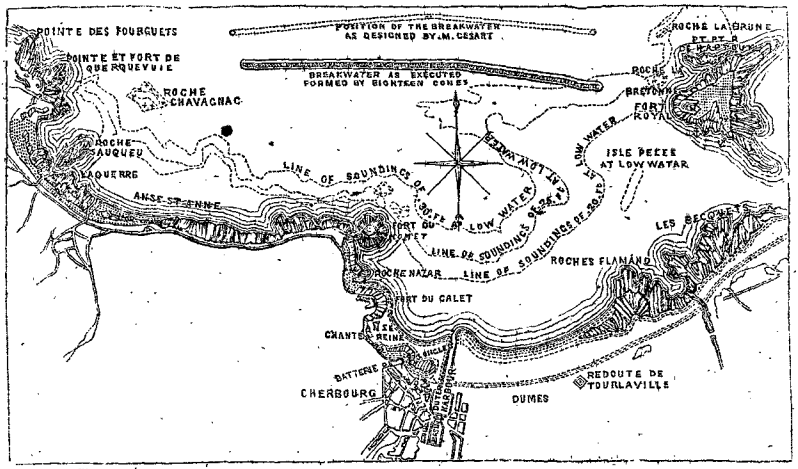
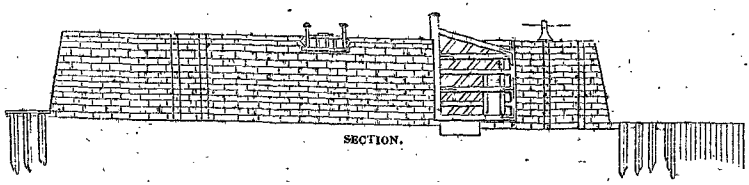
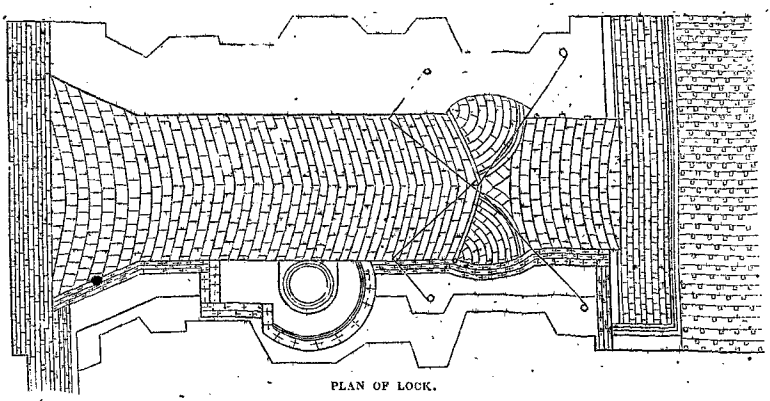


Fig. 235. PORT OF CHERBOURG.

two or three feet water: the gates of the large sluice being opened, the river Yvettes is let into the inner harbour, and by means of pontoons and other contrivances is made to plough



SECTION.



PLAN OF LOCK.

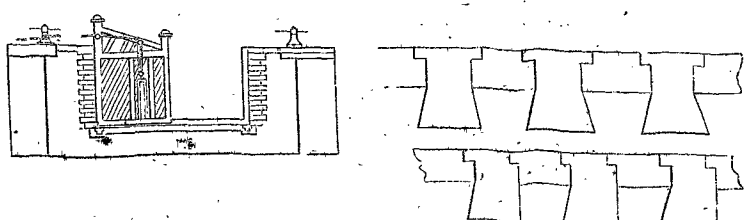


Fig. 236. LOCK AT CHERBOURG.

mud, and bear it away to sea; and the force is so great that it keeps the outer harbour scoured, where there is always a depth of 17 or 18 feet of water.

The lock between the outer and inner basin was commenced in 1786, under the direction of M. de Caux; the foundations and platform were constructed in masonry: its width is 40 feet, and its length 27 toises. It is placed on hard sand, 2 or 3 feet below which is a stratum of marl or clay, and 7 or 8 feet lower a bank of rock, the thickness of which could not be ascertained.

To prevent the encroachment of the sea during the process of laying the foundations, it was necessary to encompass the entire site by a cofferdam, 5 toises in thickness, faced with stones placed on their edges, supported at every 2 feet by rows of hurdles on a bed of heathers: this was done especially towards the sea, to prevent the washing away of the sand. A small lock was made towards the port to allow the water which the machines had already pumped out to pass off at low tide. An excavation was then made to the depth of 16 feet, sufficiently wide to allow room for the workmen around the foundations. Several obstacles occurred to prevent this depth being obtained, occasioned by the innumerable springs, which required twelve inclined mills to keep up the pumping, and which cleared out 180 cube toises per hour during the time of high water: these, however, not proving sufficient, five more were added, with vertical caps, 16 feet in height, and from 6 to 7 inches in diameter; these latter succeeded so well that the inclined mills were reduced to four.

The excavation was effected by clearing away the earth for 3 toises in width, at the extremity of the port, by the inclined mills only; and when arrived at a certain depth, the piles were driven in, on which were placed the vertical mill. As the column of water which was to be raised was from 14 to 15 feet, winches were applied proportionate to the labour to be performed, which were easily moved by twelve men, relieved by the same number every two hours, so that each mill pumped out 16 cube toises of water per hour.

When this piece was dug throughout the entire width of the lock, the same system was adopted for another width, drawing back the mills into the new position, and this was done so rapidly, that in six months the whole foundation was complete.

The pumps at first used were upon the balance principle, by which, without taking friction into account, four men raised half a cube foot of water to the height of 15 or 16 feet; but the sand in this instance accumulating, they could not be continued, and the common mills were substituted.

In digging out a foundation where the springs are numerous, it is desirable if possible to turn their course, or, if this be not practicable, to conduct them outside by means of a trough fixed to the masonry, which forms a current for the water: when they arise from a neighbouring river or the sea, they may be excluded by forming inverted funnels, the sides of which touch the mainland: a small pipe of 4 or 5 inches in diameter, laid a little higher than the level of the spring, is attached to the funnels, and the water in the pipe remaining in equilibrium ceases to flow externally; the masonry is then carried up to the summit, and the pipe filled with concrete.

After the rows of sheet piling were driven at the extremities of the platform, the first course of stone on the side of the entrance to the port was laid; it was formed of large rough blocks throughout the whole extent, and under the platform was placed a course of squared stone, of from 17 to 18 inches in height. A mass of the ordinary kind, 4 feet in thickness, was then raised; another a foot in thickness was added, laid in cement, on which was a bed of cement, 3 or 4 inches in thickness. The portion of the mass at the pointing sills was formed of several courses united together by cramps run with lead: that which formed the pointing sill was 2 feet in height, so that, being elevated 16 inches, there remained eight embedded or bonded to the pavement of the platform. Great care was taken to select the hardest stone, of from 36 inches to 40 inches cube to bed the pivots: these stones were so placed as to be tied in by the walls at the side and under the sill.

The whole of the platform was paved with stones from 4 to 6 feet in length, and 2 feet 6 inches to 3 feet in width, and from 18 inches to 20 inches thick, all having a convex surface. The strongest were selected for the pointed sills, and the whole were laid in cement, and jointed with mastic; care was taken to unite the lower course of the side walls with the stone platform, which was done by cutting the stones in such a manner that they formed a part of the facing as well as the pavement. Bolts run with lead were introduced in the situation required for the screws which were to secure the quarter circles of iron upon which the rollers of the gates run.

The pavement being completed all the joints were run with mastic, then the entire extent of the platform was covered with a bed of clay 2 feet in thickness, that the masonry might be consolidated, and the salts of the lime prevented from escaping.

The best method of constructing a platform in masonry is to form a course of headers, dovetailed into the adjoining stones so firmly that no action can detach them; this kind of work costs considerably more at first, but is infinitely stronger.

After the platform was finished, the side and wing walls were carried up with all possible solidity.

The plan shows only one pair of gates on the side towards the harbour: the omission of side-gates is a great defect, the vessels entering the port being frequently thrown against the jetties. The facing of the walls is carried up to the height of the iron collars which confine the gates, and every method is adopted to fix the ties and iron keys firmly into the masonry. In the profile and plan are shown the largest, which is fixed, and has three arms, forming a goose foot; the two extremes are placed horizontally, whilst the middle one inclines ten degrees below the others, so that the arms being united with the ties, the centre may have the same inclination, and enable it to bear the weight of the masonry. The ties, 3 inches square, are each composed of three pieces; their whole strength depending upon the thickness of the mass in which they are embedded, the pieces should be well tied together, at the same time easily separated. The ties have several holes pierced in them, to receive the keys, some of which are placed vertically in the masonry, others horizontally in large stones introduced for the purpose. The two first are horizontal, and the other is inclined ten degrees. To give additional strength to the keys two arcs are made in the stone, one 6 feet or 7 feet radius, and the other from 14 feet to 15 feet, which ties the stone against which the horizontal keys rest more solidly; grooves being cut to receive the ties, the vertical keys were fixed into eyes prepared for them.

The side walls were raised to within 6 feet of the entire height.

In arranging the turning bridge, it was necessary that the surface towards the abutments should be on a level with the pavement; when finished, one half therefore turned on a platform, and the other into a recess.

The jetties had their foundations laid 12 feet below the ordinary level of the shore; and the works were carried on without cofferdams during the period of low water. Each jetty was formed of two stone walls united by transverse walls at every 60 feet; their intervals were filled with clay mixed with a small portion of lime. The thickness above the set-off was nearly 30 feet, and at the summit 21 feet; the slope or talus being 4 feet 6 inches. When the walls were within 5 feet of their intended height, an arch was constructed, over which was formed the crowning platform.

The lines which limited the width of the jetty having been traced, sheet piling was driven in to encase the foundations; the earth was then taken out between, and the depth of the trench made as low as the heads of the sheet piles, and no more earth taken out than would allow of its being built over in the time of low water, which was about three hours and a half. Two chapellets were employed to draw the water from the trenches, which, occupying an hour, left only two hours and a half for work. Twelve feet in length of sheet piling were driven at each time, tongued and grooved and maintained in their places by two binding pieces. The thickness of the sheet piles was 6 inches, and their width 13 inches, their length being proportionate to the nature of the soil, which usually required about 12 feet; they were shod with iron, as the sand into which they entered was very compact.

As soon as the piles were driven the part of the trench which they enclosed was immediately filled up, to prevent the labour of additional pumping; and the sea from depositing sand or injuring the works. A dyke, 3 feet in height, was raised throughout the whole length, formed of fascines and covered with stones. When the foundations were laid, 12 feet in thickness was given to each wall, the first bed of facing wall was laid on plank, 4 feet below the top of the sheet piling, and after the masonry had been carried up 3 feet, its thickness was reduced to 10 feet for the first set-off, where the heads of the sheet piles were united to keep them in their place, and to fix the binding pieces firmly to the masonry, iron ties were introduced at every 8 feet. Two feet above the first set-off was another, which reduced the two walls to 9 feet in thickness, after which they were carried up with an external talus equal to one-sixth of their height, the interior face being kept perpendicular, reducing them to about 3 feet in thickness at 25 feet above the last set-off, without taking into consideration the addition by filling in solidly the spandrils of the arches. The arch of the vault, 18 inches in thickness, was formed also of stone well cut and carefully constructed. At the level of high water, rings and anchors were introduced into the masonry at regular distances.

Above the vault was laid a paving of a hard stone, 3 feet in length, 8 feet in thickness, and 18 feet in width; the joints were well secured by cement, and a fall of 4 inches was given to their surface to throw off the water. On the side towards the sea, a parapet was built, 3 feet 6 inches high, and 2 feet 6 inches in thickness, coped with stones strongly cramped. At every 60 feet cannons were placed for the purpose of defence.

The toe of the jetty towards the sea was protected by an additional embankment 16 feet in width, which had in front a row of jointed piles, from 7 inches to 8 inches in thickness, and of a length proportioned to the nature of the soil. The space between this and the jetty had other piles driven in, and their heads cut off with an inclination: on these a platform of timber was laid; the earth was then taken out for a depth of 18 inches;

fascines well bound were laid in, and the coffers of the grillage filled carefully with masonry.

The celebrated breakwater, commenced by Louis Alexander de Cessart, in the year 1783, was the most extraordinary work at this port; it was necessary to obtain a sufficiently extensive harbour for the anchorage of the French fleet after the destruction of Dunkerque, there being no other refuge on the coasts.

The difficulties were great, both in forming and defending it; some portions being carried up to the height of 80 feet, as a rampart against the impetuosity of the waves or the attack of an enemy. To weaken the power of the sea, Cessart suggested the use of large truncated wooden cones, base to base, loaded with stone, and placed in a line at half a league from the shore: they were prepared on land, floated to their destined position, filled with stone, and sunk; after which, all above the level of low water was to be built up with good masonry, faced with granite, and laid in mortar composed of puzzolana. When all that belonged to the construction was complete, the intervals between the tops of the cones was either to be closed by iron chains suspended from each other, or guarded by a floating boat or pontoon, and it was supposed that such a construction would present a barrier to the power of the ocean, and afford at all times protection to 100 sail of the line. Batteries were afterwards to be erected, which should rake the entrance at each end, and annoy an enemy approaching the harbour.

Numerous projects and experiments were tried by the engineer, in the port of Havre, upon the effects of floating a truncated cone of 150 feet diameter at bottom, 60 feet at top, and 70 feet in height. It was calculated that ninety such cones placed contiguous to each other would form a perfect breakwater. All the experiments upon the model having

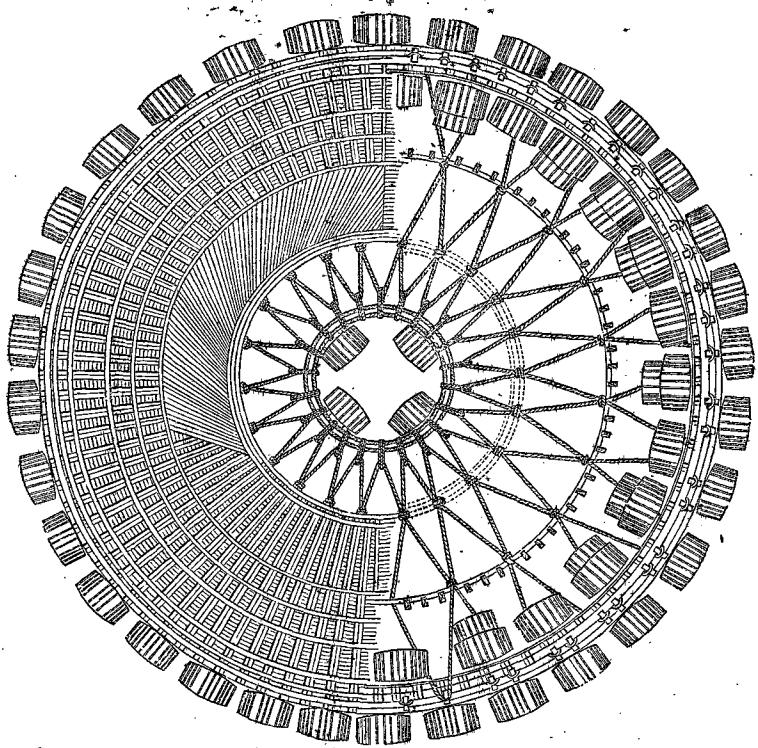


Fig. 237. PLAN OF CONE.

succeeded, the government, after making it a subject of grave discussion, and examining many competent engineers and nautical men, ordered the works to be commenced. Cessart being instructed to revise and make various deviations from his original plan, constructed on a platform previously laid down on the shore a truncated cone, the lower diameter of which was 150 feet: around this were set up ninety timbers, at a distance of about

5 feet 3 inches from centre to centre, so inclined that at the top they were gathered into a circle of about 64 feet diameter; the perpendicular height of this cone was nearly 70 feet.

Each of the inclined timbers consisted in length of five or six pieces, arranged alternately: in those having five the lower length was 25 feet 3 inches, the second length 25 feet 10 inches, the third 25 feet 4 inches, the fourth 24 feet 10 inches, and the fifth 30 feet 10 inches; altogether 132 feet 1 inch. Where six lengths were used, the four lower pieces were as those already described, the fifth was in length 24 feet, and the sixth 19 feet 7

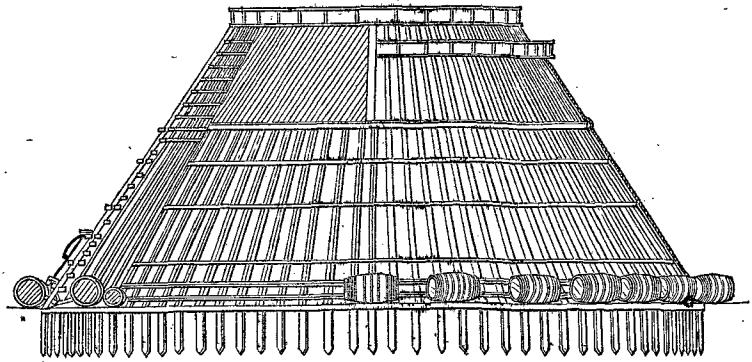


Fig. 238. ELEVATION OF CONE.

inches. The scantling of the timbers at bottom was about 13 inches square, gradually diminishing to 8 inches at the top: where they were joined, a dovetailed scarf was cut, 18 inches in length, and the two ends were secured by iron bolts. Square holes or openings were left in the timbers, 8 feet wide and 9 feet in height; one at the bottom for the purpose of admitting the casks which floated it, and the other at the fifth course, to remove them when cut from the base and floated to the surface. After the inclined timbers were hoisted, which was effected by a very ingenious process, they were bound together by six horizontal timbers on the outside, and twenty-four on the inside. On the outside beech as well as oak was used; in the first, third, fifth, and sixth courses oak, and in the second and fourth beech: these were scarfed at their ends, one 30 inches, and the oak 36 inches in length, and so placed that they corresponded with the twenty-four internal horizontal timbers in the following order: —

The first external with the first internal, the second with the fourth, the third with the eighth, the fourth with the twelfth, and the sixth with the twenty-fourth.

All the internal horizontals were halved 4 inches into the inclined timbers, and their scantling was 13 inches square. Iron bolts with nuts and keys alternately were used to secure them in their places.

A double course was afterwards added at the bottom to attach the casks, and ninety blocks were inserted between for the cables. After the slanting or inclined timbers were fitted together upon the platform, they were hoisted by eight pairs of shears, worked by as many gangs of men; when the whole ninety were in their place the horizontal timbers were fixed, which when secured, the next length was raised, and so on till the whole was completed.

After this part of the operation was performed, other horizontal filling-in pieces were introduced, varying in scantling from 10 inches by 6 to 12 by 8, at the distance of about 6 feet or 7 feet apart; fifteen of these were placed below water and as many above; the former were fixed before the cones were floated, the others after they were sunk in their respective situations; the whole was secured by iron pins, which passed through the inclined timbers, and were fastened by nuts. Five circular courses, put round the interior of the cones at the lower 36 feet of their height, prevented any injury when the casks were attached.

The ninety ends of the timbers at the summit were capped by others 6 inches in thickness and 3 feet in width; besides which other timbers were thrown across, radiating from a centre, acting as supports as well as forming a platform for the workmen.

This bold undertaking of Cessart attracted the notice of the most learned men of the time, and numerous publications issued from the press condemnatory of the principles avowed by the engineer, and for the purpose of frustrating the work. The sea, it was observed, was subjected to three great movements caused by the various winds, by the tides

and the currents, resulting from the changes of temperature to which the Northern Ocean is subjected.

When the particles of a fluid are driven in one direction, as they are by the wind, the adjoining water is required to fill up the vacant space, and restore the equilibrium which has been destroyed; waves formed by this means, it was observed, and impeded by the proposed line of timber cones, might render the water on the opposite side comparatively tranquil, but the force at the two extremities would be so great, that it would be impossible for a vessel to enter or approach the harbour. The violent impulse given to waves in a storm continues long after the gale which has produced it has subsided, and an oscillatory motion remains, and for some time works upon the great mass of water, which in this instance, it was said, would be sufficiently powerful to displace any artificial contrivances in carpentry. The agitation produced by the wind does not, however, affect the waters at any great depth; their surface is alone disturbed, for in the roughest weather at 80 feet the sea is always tranquil.

The force of the tides was still more likely to be injurious; for, being interrupted in their current, it was urged, the water would so accumulate in height, when obstructed by the pier, that it would have sufficient force to remove it from its position; and the currents which set in so violently at the bottom of the ocean would be powerful enough to displace any artificial obstruction. The two polar currents, which float mountains of ice from the frigid to the temperate regions, and which are encountered as far as the fortieth degree of latitude, were also supposed to be capable of driving away a barrier, or breakwater, placed in their course. It was also maintained, that no obstacles on land could turn aside the currents, or oppose a barrier to the grand movement of the ocean, and it was vain to attempt it: but these arguments did not weigh with Cessart. When his timbers were all firmly bolted together, and secured by the best means he could contrive, he commenced his preparations for floating them.

The execution of these immense timber constructions was confided to ship carpenters, and the whole was planked and bolted together in the same manner as the sides of a vessel: to float them seems, perhaps, the most ingenious part of the contrivance, though the method adopted was by no means new, for casks have been employed on the English coast for centuries, to buoy masses of stone required to form a mole or termination to a jetty. Pliny has described the means adopted by the ancients to float heavy bodies, and in all probability the system they practised has never been entirely forgotten: in this instance the casks seem to have been preferred to vessels; they were more under the control of the engineer, and could be more easily detached.

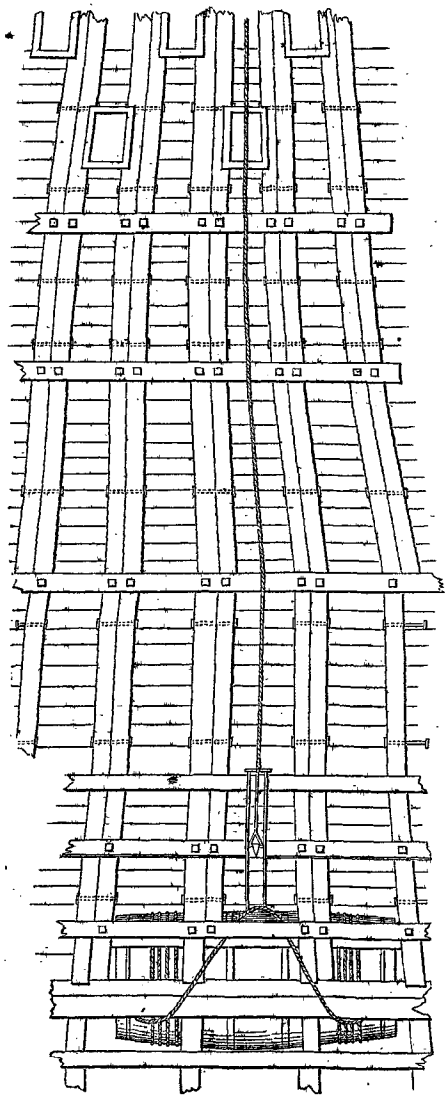


Fig. 239. FRAMING OF CONE.

The casks were 12 feet in length, 7 feet in diameter, and it was calculated that each was capable of buoying up 28,000 pounds.

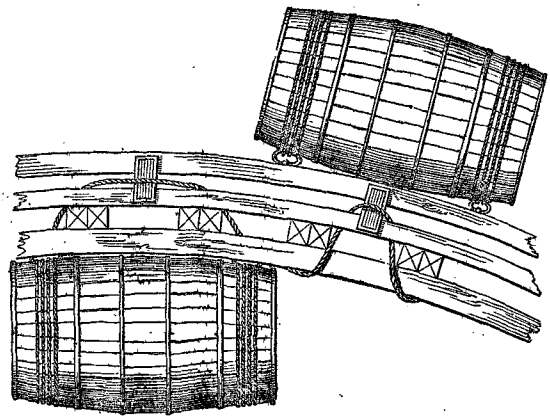


Fig. 241. PLAN OF CASKS.

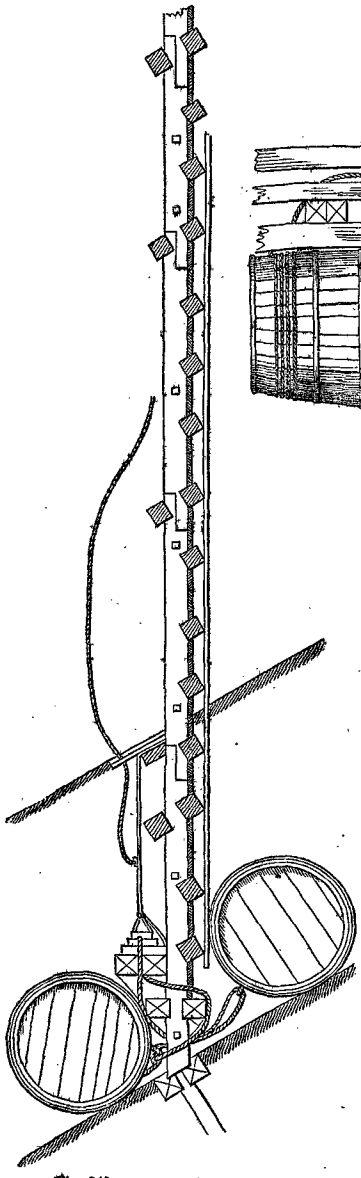


Fig. 240. SECTION OF CONE.

When all the casks were fastened to the bottom, the cones were towed to the position where the boats were to be attached: it had been previously ascertained by experiment, that four men rowing could tow one cask from 15 to 20 toises per minute against tide, and twice as fast when the tide was in their favour. Upon this calculation 250 men would be required in calm weather to tow out the cone, weighing, it was supposed, upwards of 2,000,000 pounds; but De Valon's capstan being employed, forty-two men only were required to do the same work, and they could in five or six hours move it a distance of 3000 toises; after which it would be in a position to float at all times of the tide, and could be then towed by sailing boats or by rowing.

By the 6th of June, 1781, all was in readiness with the first cone; a circuit of strong cables was placed immediately above the line of immersion, and another above the line of floatation, crossing the bottom with a grillage of ropes tending to the centre, to resist the force of the water, and to prevent the timbers spreading.

For cutting away the casks after the cone had been floated to its destined position, there were a number of hatchets or cutting instruments attached, one over the rope which held each cask; they were made to move upwards by a rope, and, from being loaded with lead, dropped by their own weight, like a pile-driving machine, and severed the rope upon which they fell. Thirty-five casks were attached to the inside, and forty-nine outside. Thirty-one of a smaller kind were added to increase the buoyancy, and ladders were provided for the numerous workmen employed. It would have been practicable to have floated the cone after it was detached from the platform upon which it had been framed and put together, by allowing the tide to rise around it, but the following arrangement was preferred.

In proper situations anchors were fixed, provided with tackle and blocks, that were

worked by a capstan on land. There were also four pontoons with similar capstans, and numerous boats, some with forty, others with eighteen oars to assist.

The pontoons were placed at regular distances, and the cone was towed out by attaching the capstan ropes to the double cable that surrounded it. A few minutes before 8 in the morning, the sea had risen 9 feet up the cone, and a slight motion indicated that it was afloat: it stood perfectly erect, balanced in every part, and needed no ballast or adjustment. The water rose a few inches higher, when a gentle south wind moved it about its own diameter from the land, which indicated that little labour would be required to tow it forwards.

The great towing cable and the hawsers were fastened to the double cincture of rope, a signal was given to slacken the ropes which attached the cone to the land, and it was immediately moved forwards by the rowers; standing out of the water 54 feet, it glided gently after the boats. About the middle of the day the vessels hoisted their sails, when it proceeded so rapidly that boats loaded with stones were fastened to it, which somewhat impeded its progress.

The vessels then reefed their sails, let go their anchors, and were attached to the girdle of the cone; the wind growing stronger, the second pontoon was gained, at forty minutes past 12; the third soon after, and at a quarter past 3 it had arrived at its destined position.

The workmen were then ordered to their posts. Cessart had arranged that the cables which held the casks should be cut at points diametrically opposite to each other, when he gave from the shore the signal to do so, which he did at half past 3; the engineers then let fall four anchors, and moored the cone to them. The ropes which held twenty-two of the casks being cut, it immediately sank 18 feet; the cords had acquired additional toughness from their strain and immersion, and although the cutting knives were loaded with forty pounds of lead, it required two strokes to separate them.

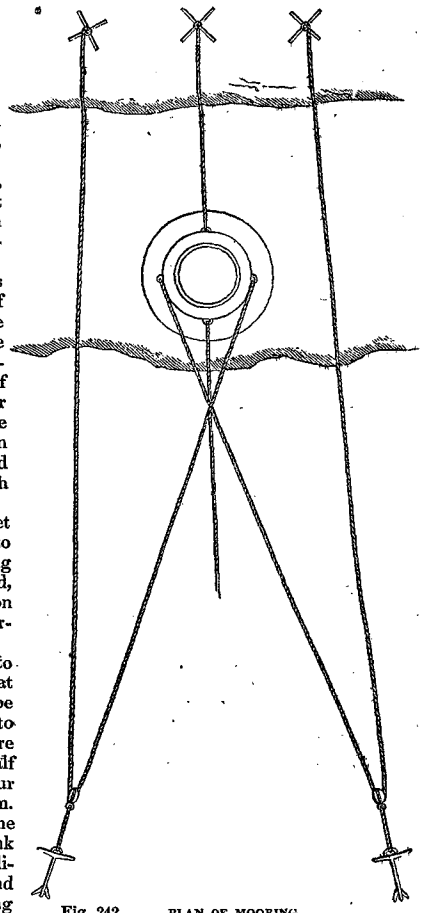


Fig. 242. PLAN OF MOORING.

The two ropes which circumscribed the cone, and which were nearly 2 feet in circumference, were then taken off.

Twenty-one cones were put together, but eighteen only were made use of, the other three being sold during the revolution. According to Cessart, the first was placed in its situation the 23d of June, 1786, and the last, the 19th of June, 1788.

These were not, however, placed at regular distances from each other. Cessart's plan was departed from; and the destruction of the timber work of the cones, a few years afterwards, was the consequence.

The second cone was placed 513 feet distant from the first, measuring from centre to centre.

The third was at 159 feet; the fourth at 184 feet; the fifth at 381 feet; the sixth at 416 feet; the seventh at 407 feet; the eighth at 448 feet; the ninth at 453 feet; the tenth at 492 feet; the eleventh at 737 feet; the twelfth at 817 feet; the thirteenth at 880 feet; the fourteenth at 905 feet; the fifteenth at 893 feet; the sixteenth at 1845 feet; the seventeenth at 1630 feet; and the eighteenth at 1310.

The total length was 12,470 feet, measured from the centre of the two extremes; the distance of the centre of the first cone to the fort on the Isle of Pelee, 3269 feet; and that

of the last cone to the Fort De Querqueville, 7685 feet, making the total width of the harbour 23,424 feet.

After the cones were placed, they were loaded with stone, and a great quantity were thrown in around their bases, and between their several intervals for the purpose of breaking the force of the sea: by the 1st of October, 1795, there had been deposited upwards of 100,000,000 cube feet of stone; or, as Cessart has given it, 381,789 toises, 4 feet, 7 inches cube.

Each of these conical cases contained as follows: —29,040 cube feet of oak, and 8705 feet of beech, an allowance of 7549 cube feet being made for waste, so that there appears to have been used for the construction of one entire cone 45,294 cube feet of timber, which was delivered at the price of about one shilling and ten pence per foot cube.

The total cost including labour, iron work, cordage, and the other materials required, amounted to about 8418 pounds sterling, or about double the first cost of the timber.

Cessart has given a full and detailed account of the cost of the barrels, vessels, building sheds, tackle employed, as well as ropes, and all other matters, from the commencement on April 1, 1783, to January 1, 1791.

The timber and iron work of the eighteen cones - - -	£102,600
Workmanship and the immersion of the eighteen - - -	65,024
Stones thrown into the cones, and to form the dyke - - -	620,004
Buildings and various other expences - - - - -	98,312
Expences for superintendence, &c. - - - - - -	16,500
Making a total of - - - - - - -	902,440

expended upon this breakwater.

The timber of the cones, in consequence of neglect and the work not having been finished, soon went to decay, and the stones they contained fell into a natural slope with those around them. From the statement made by Cessart, it appears that those placed near together lasted three or four years, and almost all the others were entirely destroyed the year of their immersion, as he had foretold.

The National Assembly in the year 1791 commissioned Cessart to prepare plans for the completion of the breakwater, when he suggested that the dyke which then existed should be covered with large masses of stone. The talus or slope towards the bay was found to have remained at an angle of 45 degrees, while on the other side, having been formed on too rapid an inclination, it had been destroyed to within 14 feet below low water, and the stone rolling out to sea had produced a talus of one in ten. He then laid down a plan for constructing a breakwater by throwing in a further quantity of stone, and covering all those parts which appeared above low water with blocks of granite, as large as could be obtained; this, however, was not executed, although in the year 1804 a number of large blocks were raised in the centre, and a battery formed upon them.

Havre de Grace is a sea-port strongly fortified, and situated at the mouth of the Seine, on its northern bank; it is in 49° 29′ north latitude, and 0° 6′ east longitude. The harbour contains three basins, within the walls of the town, calculated to receive 450 vessels.

On *Cape de la Heve*, which is two and a half miles from the harbour, on the northern extremity of the Seine, and nearly 400 feet above the level of the sea, are two lighthouses, each 50 feet in height, about 325 feet apart. At the mouth of the harbour is a round tower, constructed by François I., in 1509, over the door of which was his equestrian statue; it was the intention of the monarch to have made Havre one of his principal ports, and to have given it the name of François de Grace; he fortified the harbour, which then contained fifty large vessels, sixty smaller, and twenty-five galleys. This fleet was prepared to oppose Henry VIII. in his attacks upon Boulogne.

Henry II. made some improvements, and it was decided that the direction of the entrance, which was south-west, was too much exposed to the south-east and north-east winds; but no alteration was then made.

De Cessart prepared a design, which was not carried out, for three basins which would have contained 300 vessels, and the outer port 250 vessels. Honfleur, with its two basins, contains sixty.

The lock gates which communicate with the basin are 40 feet in width; and getting out of repair, De Cessart was employed to put in a new platform, and restore the injuries produced by time.

After having secured the new planking to the old platform by means of iron bolts, he laid down new sills 44 feet in length, which entered the masonry of the side walls at one end, and were secured by iron screw bolts at the other. After the grillage was complete, and thoroughly pinned down to the old work, the intervals were filled in with brick, laid in cement.

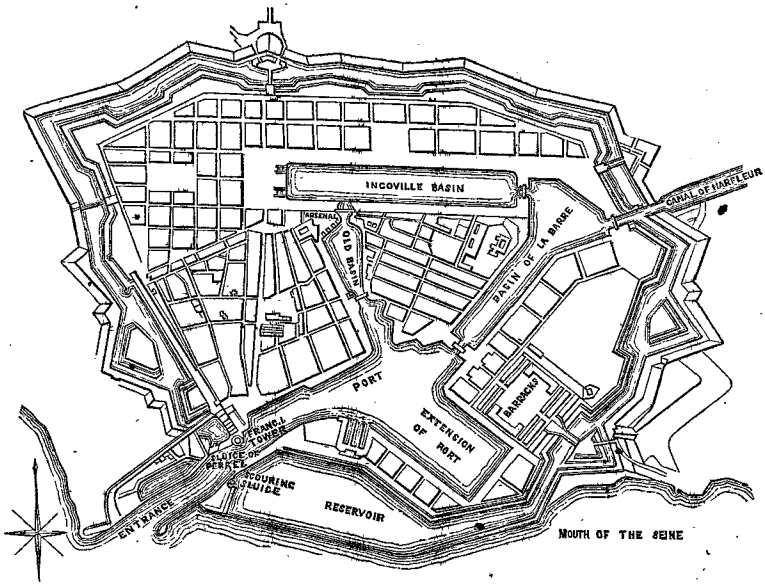


Fig. 243. HAVRE DE GRACE.

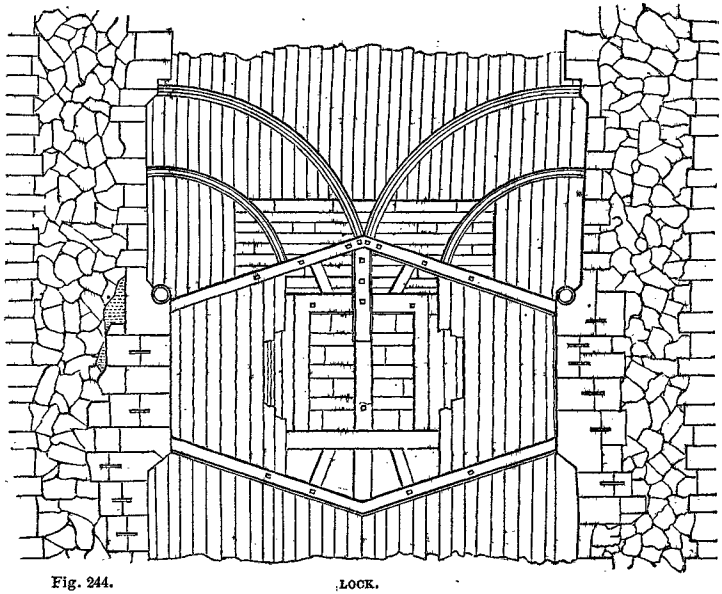


Fig. 244. LOCK.

Treport is situated in La Manche, at the mouth of the river Bresle, a league from Eu. The valley, at the extremity of which this river disgorges itself into the sea, is formed by two hills, 250 feet in height: the entrance of the port is situated at the foot of the west hill, on the slope of which stands the town.

The village of Merse occupies the foot of the other hill, on the side of the valley, the breadth of which is here 800 toises.

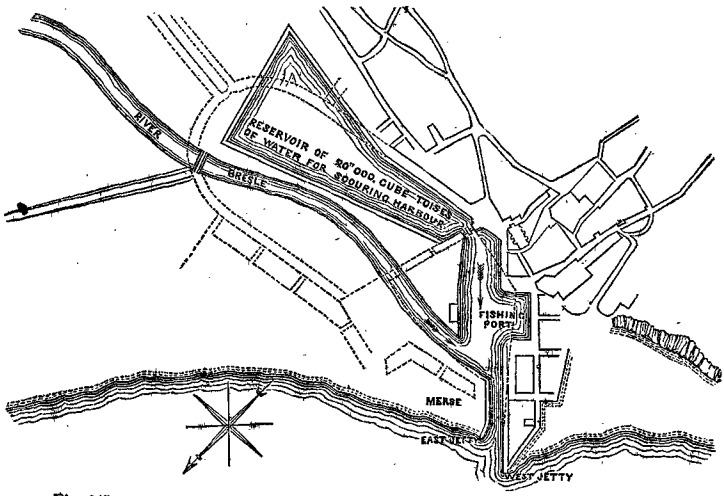


Fig. 245. TREPORT.

The mouth or entrance is exposed to the winds between west-north-west and south-south-east. This position renders it easy for the access of vessels, as when they miss the port, they can run out again without being exposed to the danger they incur at Dieppe.

When vessels bound to Havre, Fecamp, or Dieppe, entering the channel by winds blowing between west-south-west and north-north-west, miss the entrance of these ports, they invariably run aground at the mouth of the Saone; this they would avoid by making for

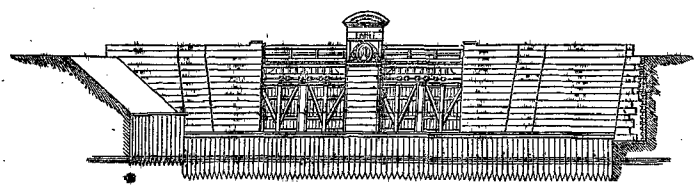


Fig. 246. ELEVATION OF SCOURING SLUICE.

Treport; its position is therefore most important as a refuge harbour. Du Cessart improved this port in the year 1778, and constructed the scouring sluice by which the harbour is kept constantly cleansed; it has two passages for the water, each 21 feet in width, separated by a pier 8 feet thick, terminated at the two sides by walls 10 feet in thickness, with wing walls and returns.

The platform fills the space between the walls, both above and below; below the apron is a row of sheet piling, which keeps the earth of the foundation from washing away. Above these are two rows of sheet piles, which prevent the work from being undermined.

Each of the two passages is closed by two gates, 12 feet in height; a wooden bridge, 13 feet in width, affords a communication across the sluice. The upper platform is constructed of timber, so that a reparation can be effectually made, without the walls sustaining any injury. The pivots and sockets on which the gates move are of cast-iron, each weighing 193 pounds: the lower rail of the gates is kept 2 inches above the level of the platform, a sill of the same height fills the space, and prevents the loss of water.

Turning gates made in the ordinary way lose a great quantity of water in the upright joints, as well as through the space between them and the facing of the piers; to remedy this De Cessart made a circular indent in the side walls, radiating from the centre of the turning post, and by this means effectually closed the joint at the side. There is also an objection in their being centred at two-thirds of their width, the one side being double the other. The gates open with great velocity, which strains them as well as injures the platform: when the sea is violent the waves striking the gates at low water forces them open, and they remain so until the water they retain is in equilibrio with the power applied to it. The wave then suddenly returning, the gate is closed with great force against the shutting post, which materially injures not only the post but the work. To remedy this inconvenience De Cessart centred these gates in such a manner that the difference of their sides

was not more than 6 inches, which sufficed to open them. The sea at Treport rises 8 feet higher at spring than at neap tides; by establishing the top of the gates at the level of

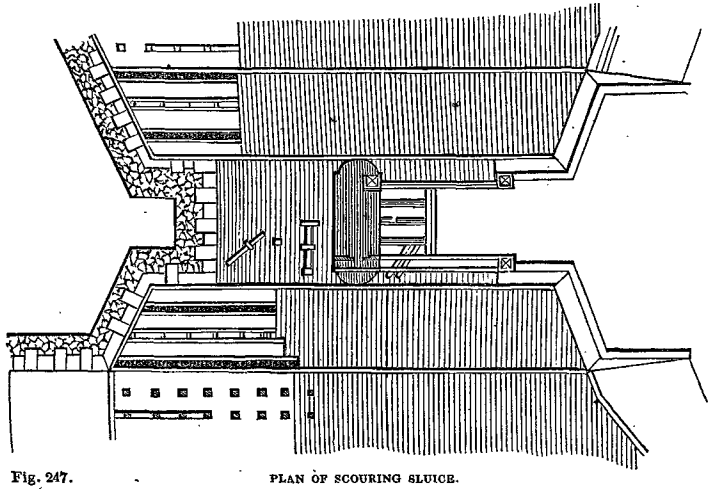


Fig. 247. PLAN OF SCOURING SLUICE.

high-water spring tides, the sea would only mount 12 feet above the platform once in a tide; but to retain this weight of water longer, he made the platform 13 feet 10 inches lower, which gave the advantage of using the sluice five or six times during each tide.

De Cessart proposed the construction of a vast reservoir to contain 20,000 cube toises of water, and to turn the river, but this project was not fully carried into effect.

Dieppe is situated at a distance of 22 leagues from the English coast, and is the only port in the Channel where the ordinary spring tides rise 30 feet, and the equinoctial from 32 to 34 feet.

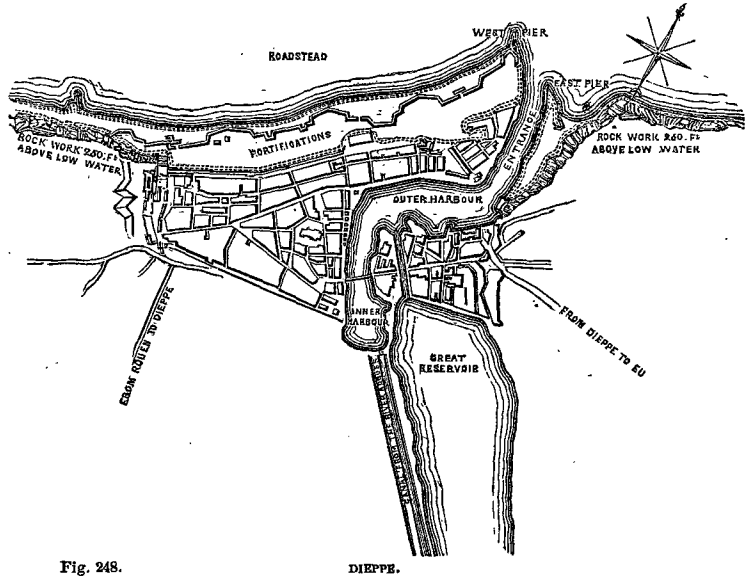


Fig. 248. DIEPPE.

The town is situated in the midst of a valley, 600 toises in breadth, watered for two leagues of its length by the river Argues; the valley lies north and south, and the wind seldom continues to blow in this direction more than forty-eight hours at a time. It is

also sheltered by two hills which rise from 200 to 300 feet above the level of the sea, affording to the vast basin a calm water, of great value to all vessels that frequent this coast.

The port of Dieppe being situated at the mouth of a river, a deposit of sand had been allowed to accumulate from time immemorial, and the utility of it as a refuge for ships was destroyed; the rising of the ocean had also produced another evil; the right bank of the valley was covered with shingle, as well as with the debris of the left, which had been washed away; by these obstructions the course of the Argues was changed, and a mouth opened for it at the foot of the east hill. The works at this port, as the construction of the timber jetties, were carried on at various times, as necessity suggested, and without any regular plan being laid down; nevertheless vast sums were expended upon the west jetty, as well as upon the prolongation of the *Polet;* and when this costly work was abandoned, the gravel accumulated to a height of 12 feet above low water; so that in the year 1775, it had become only a retreat for small fishing boats. Another great inconvenience was the want of fresh water in the harbour.

De Cessart, who was named engineer-in-chief for the improvement of the port, finding that off the coast the tide rose to so considerable a height, did not venture to adopt the usual practice of building in cofferdams, where they could only work at certain hours, but used caissoons, taking care to surround them with one or more rows of sheet piles, driven until they ceased to answer the ram. In excavating foundations for marine works, he observes that it is rare to meet with earth whose particles are sufficiently adherent to prevent filtration, the deposits on the shore being so various that the water freely passes through them.

The vessels usually frequenting this port required from 15 to 20 feet of water, and allowing for the plunging of the vessel, the natural ground ought to be at least 22 feet below the level of high water. Many cofferdams have been constructed of this height, and the works constantly carried on; he mentions one formed by Thumberg in the Baltic at Carlscrona, which was 84 toises in circuit, sustained 20 feet of water, and contained a space of 4000 superficial toises.

The jetties are composed of masonry 50 toises at the base, crowned by a platform 42 feet above the level of low water, and 7 feet 2 inches below that level, so that the total height from the foundation to the parapet was 49 feet 2 inches; De Cessart only formed the earthwork preparatory to this construction, which was sufficiently ingenious to admit of a

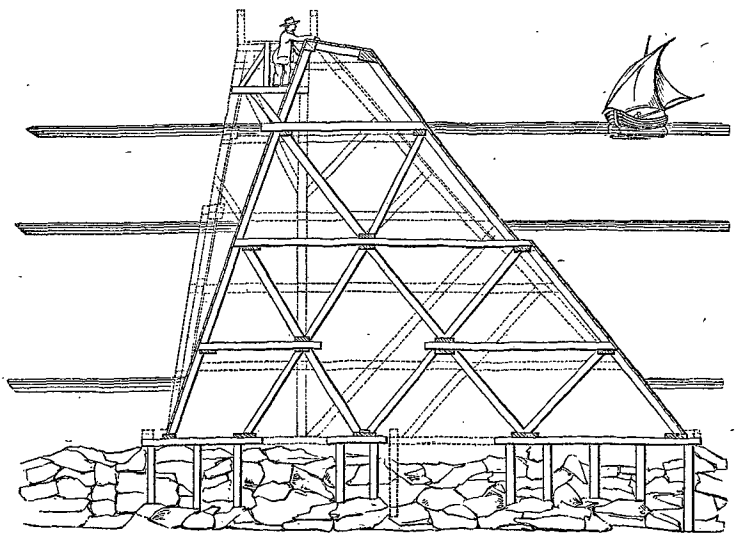


Fig. 249. MOLE.

description: it was partly executed, but in 1793 it was demolished, and the timber sold. A base of about 50 feet was laid out by driving piles into a hard bottom; these were capped at the extremities, and the heads filled in with stones; on this were placed three timber caissoons, 36 feet in height, framed and planked over, and the interior filled with earth: the slopes were made to vary.

The mole stood 6 feet above the level of high water; on the side towards the sea the inclination was at an angle of 60 degrees. The whole may be considered to consist of three

prismatic caissoons, two forming the base, the others placed above them; these were boarded on the outside, and filled with stone, gravel, and earth. The length of the mole was 160 toises; six drains were formed to carry off any water that might find an entry to it.

De Cessart also executed the sluice for scouring the harbour by means of a caissoon, in length 54 feet 8 inches, in width 93 feet, and in height 15 feet; the area was 5080 feet.

To put the platform together ten rows of piles, each containing eighteen, were driven; they were in length 10 feet, and 9 inches square, the heads of the piles were capped, and the whole brought to a level; on this was put the bottom of the caissoon, composed of four outside timbers, 14 inches square, and four others laid within of the same scantling.

The width was divided into three bays, of 21 feet 4 inches each; these bays were filled in with timber 10 inches square, nicely jointed, and made level at the bottom; over these were other transverse timbers securely bolted to the bottom, and between them a course of 4-inch planks, also crossing the lower timbers at right angles. The whole was secured by four iron bars, 2 inches in thickness, which were screwed up and rendered the platform a compact mass.

After this was done, a course of timber 10 inches by 8 was laid around the outside, and above this, four others of the same scantling, into which the uprights of the sides were to be framed; these were 15 feet in height, and composed of ninety-six upright timbers, 12 inches by 6, lined on the outside with 6-inch planks, and again crossed by others 4 inches thick; additional strength was given by forty interties, 18 feet 6 inches long, and 12 inches by 10. When the caissoon was ready to float, a layer of moss and clay was introduced beneath it, to prevent any infiltration from taking place.

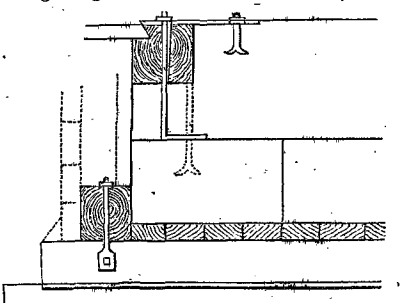


Fig. 250. FRAMING.

The weight of the caissoon was 761,342 pounds, and it drew 2 feet 1 inch and 4 lines of water.

It was towed out by two capstans and ropes, and in less than ten minutes was firmly fixed in its place. By some accident the bottom carried with it some of the small timbers of the platform, upon which it was constructed, which prevented the caissoon from being laid on the bed of moss prepared to receive it. These were removed by passing small rollers by means of ropes under the bottom, which fished out all that obstructed it.

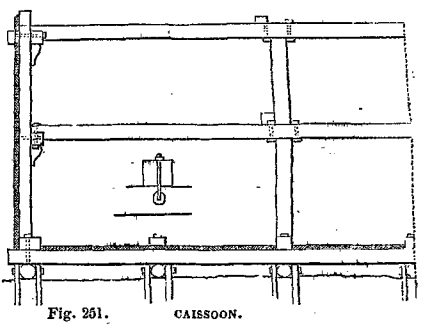


Fig. 251. CAISSOON.

To attach the lower course of masonry to the timber platform, each alternate stone was usually fastened by two bolts, one entering the stone, and the other the main timber on which it rested, but De Cessart, not finding this always effectual, adopted another plan; after the first course of stones was placed upon the platform, he secured the second by irons, and the timbers which were worked into the masonry to receive the planking of the aprons above and below the lock, were attached by bent irons placed at regular distances of 3 feet, 14 lines in thickness.

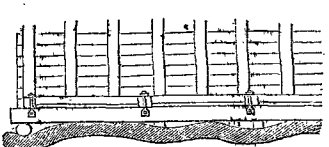


Fig. 252. ELEVATION.

Bordeaux is a fine harbour on the Garonne, and although situated at a distance of about seventy miles from its mouth, there is sufficient depth of water in this noble river to enable large vessels to come up to the quays of the city.

At the entrance into the river, the distance between Point de la Coubre on the north and Point de Grave on the south is nearly four leagues; there are, however, extensive sand-banks which are dangerous to the navigation, and some considerable rocks, on one of which is placed the celebrated Tour de Cordouan, which has now a revolving light, sometimes showing brilliantly, then feebly, and then eclipsed; in clear weather it may be seen for eight or nine leagues.

Marseilles is a sea-port of great antiquity, and situated in 43° 17′ north latitude, and 5° 22½′ east longitude. The harbour, surrounded by strong fortifications, is a capacious

basin, 525 fathoms in length, and 150 in breadth; the depth at the entrance is 18 feet, and in the harbour from 12 to 24 feet, which is maintained by the constant employment of the dredging machines.

The lighthouse is situated on the Fort St. Jean, which is on the north side of the entrance to the port, and at some distance from the north of the city is the lazaretto.

On the island de Planier is another lighthouse, 131 feet in height, which from the excellence of its revolving lights may be seen in clear weather at a distance of seven leagues.

There is a slip for ship-building constructed of stone, the length of which is sufficient to admit a man-of-war, and the width at top 47 feet. The whole is ingeniously roofed in, with flights of steps descending to the various levels.

Rochefort, a fine maritime city, had its port greatly improved in 1664, under the orders of Louis XIV. The slips for ship-building were the finest in France; they were connected with each other and had but one entrance, with a pair of lock gates to shut out the sea. The first entered was calculated from its depth to receive vessels of the first rate; the second had its platform 7 feet higher, two vessels could enter, and the water at low tide being suffered to run out, the gates were closed, and the two vessels were in a situation to be caulked at the same time. In the side walls were small aqueducts, by which the water could be admitted, when it was required to float them again out to sea.

To use the upper slip for the construction of a vessel, without being deprived of the lower one, grooves were contrived in the portion where the separation took place, into which planks were dropped, which kept the water from entering, as the intervals between the two ranges of planks were filled with clay in the manner of a cofferdam.

In the construction of this double slip, as great inconvenience was experienced from the working of the springs, a well was sunk in the bottom of the upper slip, which, by means of drains, collected all the water that would otherwise pass under and around the works; from the well it was pumped out by an hydraulic machine made for the express purpose. It is undoubtedly most important to keep slips perfectly free both from the action of the springs, and from the water intended to pass through the locks, but this should be accomplished without the aid of machines.

At low water they should be perfectly dry, to effect which it is necessary that the bottom should be laid a foot higher than the ordinary level of low water in the port to which they belong. Vessels drawing from twenty to thirty feet of water when loaded require less when their freights are discharged, and the height to which the tide rises must determine the level to be given to the slip.

To render the entrance gates at Marseilles water-tight, they are stopped at all the crevices and joints by caulking, and the water is thus effectually shut out. When the wooden platform is laid too low, it is liable to be covered with mud, and to prevent the opening of the gates; this was guarded against in the present instance. The length and width were also made proportionate to the vessels they were intended to receive.

In the slips at Rochefort the entrance lock was first formed with sluices at the bottom, which allowed the water from the springs to drain off.

To form the foundations the same precautions were adopted for laying the timber platform as for that of a lock of a canal; planking and piling were made use of throughout, and the masonry fixed with great care after the heads of the piles were cut off. When all the intervals between the heads of the piles were filled in, a mass of brickwork or masonry 3 feet in thickness was laid in hydraulic mortar or cement over the whole area; then cross timbers were so placed upon it, that they formed sleepers to an inclined plane, made by the longitudinal timbers which rest upon them. All the intervals were again filled up with masonry, and an inclined floor was then laid, having a fall of 8 or 9 inches from the upper end.

The piling was carefully executed, and every precaution taken to render the platform firm and secure.

Toulon, which takes its name from Telo Martius, is a very considerable port, on the shores of the Mediterranean, and distant from Paris 220 leagues. The arsenal and magazines are the finest in France, and there is every requisite for a maritime establishment; a quay wall and slip were built in deep water by means of a caissoon, which Belidor thus describes: "The quay being too narrow, the walls were advanced 40 feet or more into the sea, where it had 20 feet depth of water. The lines being set out, two machines were employed to raise the mud between them until a good bottom was obtained, which was perfectly levelled; the foundations were then formed, 18 inches in width, of a bed of gravel, and chippings of stone, spread level with great care."

Caissoons, or cases of timber, upwards of 60 feet in length, 13 in width, and 25 in depth, well caulked and pitched, were made use of in deep water; these were afterwards taken to pieces, and all except the bottom again served for other caissoons to lengthen out the work; about 200 feet in length being operated upon at one time.

After these caissoons had been put together on shore, they were launched, floated to their right situation, and then maintained in an upright position by ropes which passed

through rings attached to piles driven conveniently for the purpose. When the masons entered, they commenced their work, by filling up the voids between the bottom timbers with puzzolana and lime, mixed with gravel and chippings of stone; upon this, properly levelled, was built a stone wall 8 feet in thickness, the external faces of which were carried up with blocks from 12 to 14 inches square, dovetailed into each other; the space between being filled with moellon.

As the caissoons sunk as they were loaded, it became necessary to keep them from swerving or getting out of their line, and greater attention was required when they had reached within a short distance of the bottom. Proper examination being made of their position, when found correct and perpendicular, they were loaded with the rest of the materials to be employed in the construction, which, when raised within 2 feet below the level of high water, was allowed to remain for a considerable time to acquire the requisite hardness, after which the several partitions which separated the caissoons were removed, and the spaces of 2 feet between them filled up, and the wall completed throughout its whole length. This portion of the work required that sheet planks shod with iron should be driven in a manner to surround the several intervals, after which beton was let down into them, and the facing brought up on both sides to unite with the others, when it was made good throughout.

In the ports of the Mediterranean slips were made at very early times for the construction and launching of vessels of considerable draught, and also for the purpose of hauling vessels that needed repair on shore.

When they required careening, a frame made of timber, and called a cradle, was placed under the vessel and supported it in a state of equilibrium, until it was brought to the stocks and shored up. This cradle, of a very early invention, was formed of three longitudinal timbers, 20 inches square, which extended the whole length of the ship, one being under the keel, and the others at the side a little above. The vessel was girded with strong cables to these timbers, which were mounted on eight rollers that were turned by means of handspikes. The form given to the slips was that of a wedge, the inclined plane of which was in length about 220 feet; the bottom projected into the sea, where a timber platform terminated it. Its inclination, like that of the stone bottom, was equal to a fourteenth, the rise being about 5 inches to every 6 feet, which permitted the vessel when launched to glide easily into the water, without subjecting it to any sudden shock or interruption. As the vessel had neither its cargo nor ballast, 16 feet water was reckoned sufficient for it to float.

Another slip at Toulon was commenced by taking out the ground to a solid foundation, for 220 feet in length, and 60 in width, using for the latter part of the operation the dredging machines employed for cleansing the harbour. The bottom had a sufficient fall or inclination towards the sea, at the point where the slip was commenced. The stocks were established 18 feet below high water at one end, and 22 feet at the other; the construction was carried on by the means of caissoons, 60 feet in length, and of a depth sufficient to maintain 4 feet above the level of the water at the highest state of the tide. They were fixed in their places and inclosed in a space 230 feet in length, and about 60 in width, and in this case the caissoons were not loaded, but the water was suffered gradually to enter and sink them; afterwards they were loaded with the stone intended for the constructions, and the openings which admitted the water being closed, the water they contained was pumped out. Another precaution, taken after the caissoons were grounded, was to plank and pile around them at the points of their junction, and form a clay dam, so that when the ends or divisions which separated the caissoons were taken out, the work might be made good and the wall continued in its construction without any interruption. This arrangement had very considerable advantages over the preceding, and was another step towards improvement.

Quay at Rouen, built by De Cessart. — The great road from Paris to Havre and Dieppe, passing along the ancient quay of Rouen, it was found inconveniently narrow, and in 1779, a new quay was completed, 120 feet in advance of the original wall.

The total length of the new quay was 110 toises; this was divided into seven equal distances, by caissoons 66 feet in length, 16 feet wide, and 14 feet high, their base containing 1056 square feet. Ninety-two piles were driven, 3 feet 6 inches apart, in the thickness of the wall, and 3 feet in the length of the caissoon; each pile bore the weight of 18,633 pounds, for the wall alone, and adding one half more for the weight of merchandize placed on it, would then have 27,000 pounds.

All the piles were from 12 to 15 inches thick, driven with a ram weighing 1200 pounds, falling 20 feet, each pile receiving a percussion equal to 300,000 pounds. The heads of the piles were cut off 6 feet below low water, at 12 feet behind the wall; piles were driven at every 6 feet, to attach land ties, which supported the masonry; sand and gravel were then thrown from the inside of the wall, to form a slope on the river side of sixty degrees, which extended 60 feet into the river, so that vessels of 400 tons could approach the quay at low water.

The most ingenious part of this arrangement is the formation of an embankment in the bed of the river, into which the piles were driven, and of a second embankment over it, in which the caissoons were placed. After the wall was constructed, the whole was then backed in by earth brought from the neighbourhood, and the spacious quays thus obtained

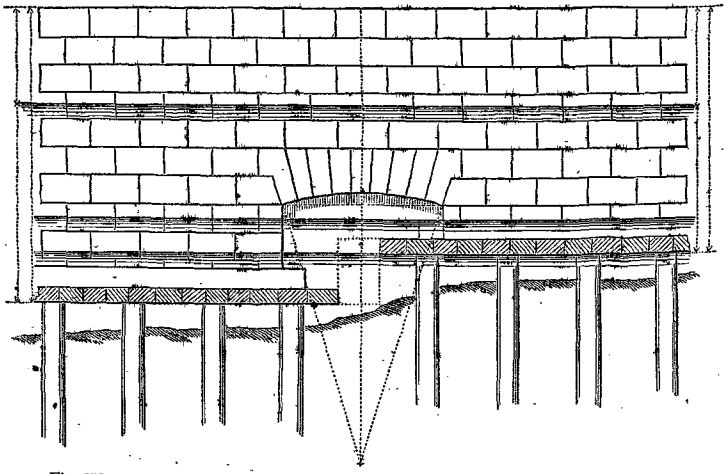


Fig. 253. QUAY WALL, ROUEN.

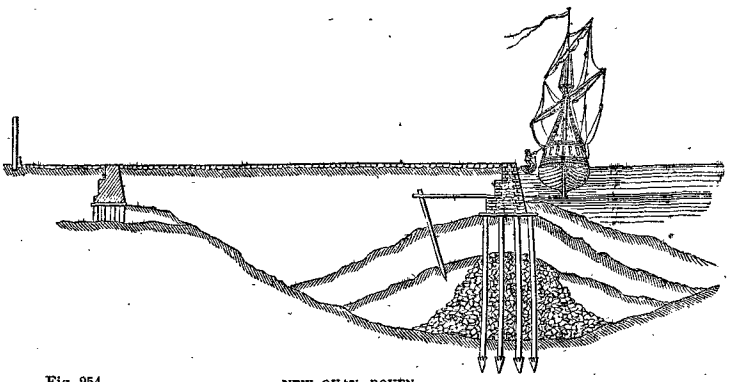


Fig. 254. NEW QUAY, ROUEN.

were paved throughout. To maintain a level above low water, where some difficulties occurred in cutting off the heads of the piles, arches were turned 7 feet span, and the whole most ingeniously connected.

Cordouan Lighthouse. — Since the time of the ancients there has never been a more important and superb pharos erected than that of Cordouan; it is situated on a rock forming an island at the mouths of the Garonne and Dordogne, and but for the warning it affords, the vessels entering or leaving would be always in danger of wrecking. It serves as a sea-mark during the day and a lighthouse at night; there are only two passes, the one called the *pas des anes*, between St. Saintonge and the tower of Cordouan, the other between the tower and Medoc, called the *pas des granes*, both equally dangerous to vessels that may be unfortunately surprised by a heavy westerly wind. The tower is in 45° 35′ latitude, and 16° 53′ longitude, two leagues from Bordeaux. All around it are rocks covered only 3 or 4 feet, against which the billows rise to a great height, and break with tremendous violence, rendering the access to this tower very difficult; vessels of three tons only can approach it by a single channel, about 100 feet in width; at 600 feet from the tower there is a sand on which they can run aground at the moment of low water, of which advantage must be taken, the rest is nothing but unapproachable rocks. This magnificent tower, 169 feet high from its foundations, was built in the reign of Henry II. by Louis de Foix, who com-

menced it in 1584, and finished it under Henry IV. in 1610. Navigators consider it the finest in Europe, and the boldest in execution.

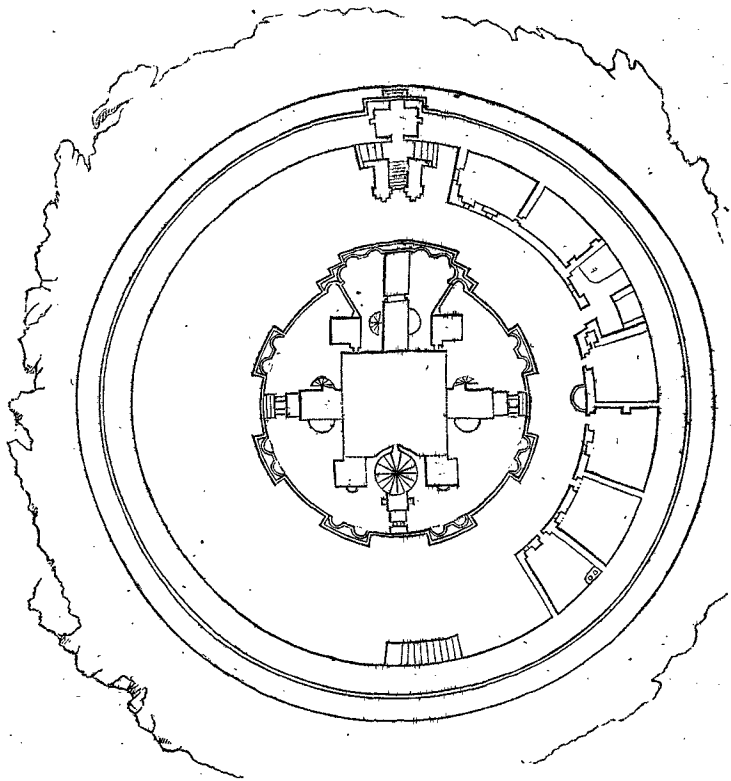


Fig. 255. PLAN OF THE LIGHTHOUSE AT CORDOUAN.

The island upon which it is built, being dry at low water, and wholly covered by the tide at high water, exhibits a bare rock 500 fathoms in length from north to south, and 250 fathoms in width from east to west; the base of the edifice is a circle of 135 feet diameter, over the whole extent of which the constructions are of solid masonry, except where the stone stairs are introduced, which commence at the level of high water; near them a cavity is formed 20 feet square, which serves as a cistern to hold fresh water, this rises about 8 feet, including the arches which cover it: the remainder of the area is entirely composed of solid stonework, brought up to a level platform, which, as the walls batter all round, reduces the diameter to 125 feet. The staircase, which is carried up in the solid, commences 4 feet above the rock in the east side, and serves to mount to the platform; the ascent to it is by a ladder, and the opening is closed by strong wooden doors.

On the platform is a circle of 100 feet diameter, around which is a wall 12 feet 6 inches in thickness, battering up to the height of 12 feet, where its thickness is only 11 feet; its object being to resist the action of the western seas.

On this circular platform is constructed the tower which forms the lighthouse, the diameter of which is 50 feet, and the whole is carried up to the height of 115 feet: the several stories diminish as they approach the summit, on which was originally a stone lantern, or rather dome, supported upon eight stone mullions, with openings between them for the passage of light.

The 25 feet space between the tower and the outer circular wall was occupied by several small apartments, which served as lodging rooms for the attendants and store rooms.

The building is composed of four stories, and the apartments they contain were highly

decorated; externally, the lowest is of the Doric, the second the Ionic, the third the Corinthian, and the uppermost or lantern of the Composite order.

On the ground or lower floor is a vaulted hall, the dimensions of which are 22 feet square, and the height 20 feet; it contained two wardrobes, and many other conveniences obtained out of the thickness of the walls.

Over this is the grand saloon 21 feet square, and 20 feet in height, a vestibule, two wardrobes, and other conveniences, the whole vaulted with flat elliptical arches.

The third story was appropriated to the chapel, which was of a circular form, covered with a dome; the internal diameter was 31 feet, and the height, including the hemispherical dome, 40 feet. The interior was decorated with paintings and mosaic; the light was admitted through eight windows, and in the centre was a circular opening 4 feet diameter, protected by a balustrade.

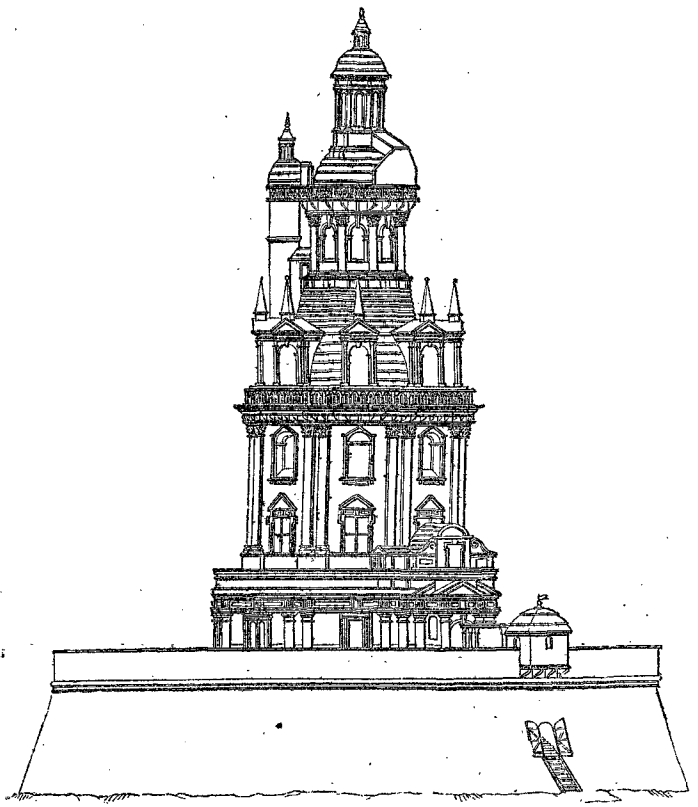


Fig. 256. ELEVATION OF THE LIGHTHOUSE.

The diameter of the lantern, which formed the third story, is 14 feet, and around the exterior is a stone balcony, the internal diameter of which is 21 feet, forming a solid covering to the chapel below it. On the outside are eight Corinthian pilasters, which answer to the mullions, between which are as many glazed windows, 2 feet 6 inches wide, and 7 feet high.

The inside of this story is 20 feet in height up to the square, which is covered by a hemispherical cupola, making its whole height 27 feet; this cupola, which is formed with stone, and built very solidly, serves as a basement to the lantern, originally 5 feet diameter internally, and 9 feet externally, and the height above the cupola 17 feet; in the middle was an opening 18 inches diameter; through this the smoke passed into a smaller funnel, 2 feet 6 inches diameter, in which were a number of small holes that allowed its escape. The upper funnel or turret was capped with solid stone, 31 feet above the floor of the lantern light.

The total height of the building above the base of the tower, is 146 feet, and above the surface of the rock 162 feet.

In 1727, the summit underwent a change; the former lantern having been destroyed, one of iron was substituted. This was done under the direction of M. Betri, engineer-in-chief at Bordeaux, who contrived a cage of iron, or lantern, formed of four principal pillars, supporting a cupola, finished with a large ball and vane 36 feet above the platform; the lantern was entirely open, and the smoke could escape on all sides; the ceiling, which was circular, was formed into a hollow cone or funnel, the top of which was bent downwards, about 3 feet; the entire sloping surface of the cone was covered with tin plates, which became so many reflecting surfaces, and occasioned the light to be seen from a greater distance.

Reflected light was made use of here for the first time about the year 1780, when

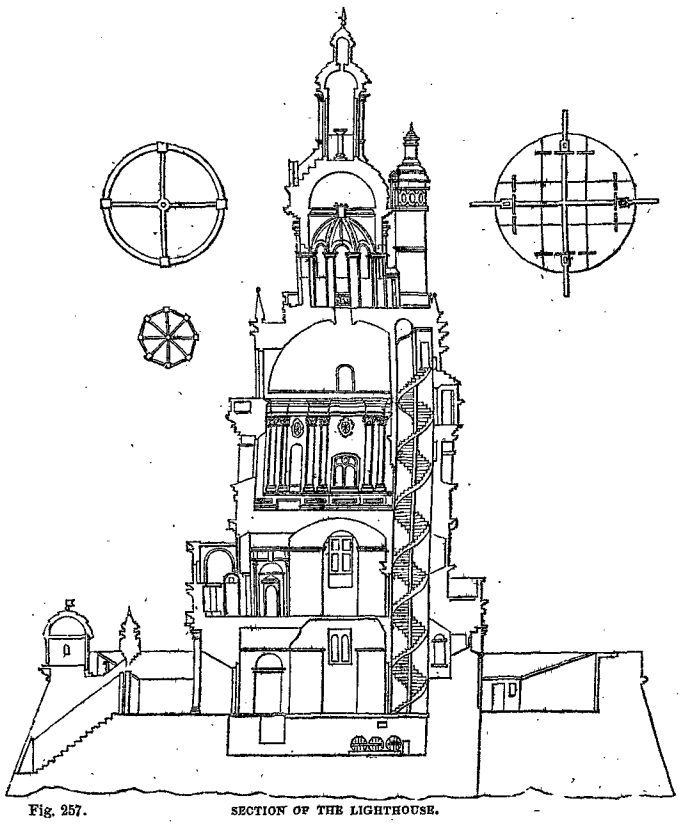


Fig. 257. SECTION OF THE LIGHTHOUSE.

M. Borda introduced an Argand lamp in the focus of a parabolic mirror; the reflector was a sheet of copper plated with silver, with a focal length of about 3 or 4 inches; the diameter of the outer edge was 21 inches.

The curvature of the reflector was truly parabolic; the light issued from a mathematical point, and the rays were reflected from a mirror, placed exactly parallel to the axis of the generating curve; the beam of the projected light was that of a cylinder having a diameter equal to that of the mirror. The light, however, in this form, was nearly useless, and it was found necessary to give the rays a divergence, that they might extend to a greater portion of the horizon. To effect this, the burner, which was about an inch in diameter, was made to produce the luminous rays at a small distance from the focus, and instead of being reflected in a mass of cylindrical or parallel rays, they were projected in a cone having a divergence of about forty degrees.

To obtain a sufficient quantity of light it was necessary to have a number of parabolic

mirrors; and sometimes as many as eight are employed, mounted upon a frame, their axes being all parallel to each other, and so placed that the light reflected by them is formed into one conical beam.

A revolving light was produced by attaching the frame to a horizontal axis, made to turn round by the aid of machinery.

A stationary light only requires the reflectors to be placed round a circular frame, with their axes on the radii of the circle. The illumination, however, is not equally intense at all azimuths, but strongest in the direction of the several axes, and weakest in that of the lines bisecting the several angles formed by each pair of contiguous axes.

Auguste Fresnel, of the Academy of Sciences at Paris, advised that refracted light should be generally introduced into the lighthouses in France, having a plane convex mirror with a focal distance of about 3 feet, formed of crown glass, which was thought less liable to striæ than flint. The first lens was polygonal, and consisted of several pieces of glass, separately prepared, and united together, but afterwards spherical lenses accurately ground supplied their place.

The divergence of a cone of light projected by such a lens, is not more than 5° 9′, and is much less than that produced by the parabolical reflector.

The largest lens at the French lighthouses projects a cone of light equal in intensity to eight mirrors of the best kind. The luminous cone in one case is only that portion of light which falls on the surface of the lens, and it might be imagined, that this could never equal in effect that produced by the parabolic mirror; but the polish of the latter not being perfect, a great quantity of incidental light is lost, which is a chief reason in favour of the lens.

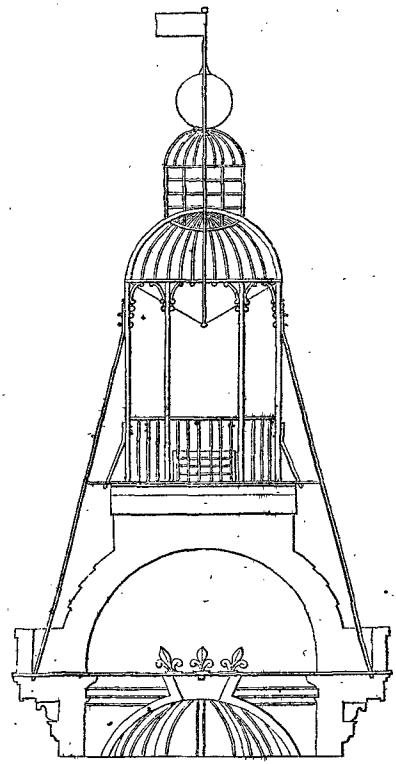


Fig. 258. LANTERN.

When refracted light is adapted to the revolving system, the frame which carries the lenses has eight sides, to each of which one is attached; the whole, however, are so arranged, that all their axes are in the same horizontal plane, and meet in the common focus where the lamp is situated, forming one large octagonal prism.

To prevent any loss of light, a second frame is placed above the first, the sides of which form the frustum of an octagonal pyramid, and incline fifty degrees; on each of these sides is another lens, having its focus in the flame of the lamp. The rays which fall on the inclined lenses are refracted parallel to the axis of the lens, and are then reflected into the horizontal direction, by plane mirrors, placed above the upper frame. Curved reflectors are sometimes used, above the frames which contain the principal lenses.

Fresnel also substituted a very elegant contrivance for the upper lenses and mirror: a series of triangular prisms had their axes arranged in horizontal planes, and so adjusted that the light falling on the face next the flame was thrown upon the back of the prism, where it was totally reflected; and by a second refraction at the third side of the prism, it obtained its horizontal direction.

For fixed lights of this description, a sufficient number of lenses are required to form with them a cylinder so that an equal diffusion of light should be spread over every part of the horizon. Some French lighthouses have a refracting apparatus consisting of a belt of thirty-two lenses, arranged polygonally.

Such a light is described by Fresnel in his memoir on the subject, published in the year 1822, and his system is applied to most of the lighthouses on the French and Dutch coasts.

The Argand fountain lamp, with a burner an inch in diameter, tipped with silver, is made use of; and Fresnel invented one with a series of concentric burners; for lights of the first class, there were usually four, protected from the excessive heat by a superabundant

supply of oil, which by means of machinery was made to overflow the wicks continually, and a sufficient quantity of air was obtained through the aperture of a lofty chimney; the oil of colza, which is produced by the seed of the wild cabbage, is made use of, and in some instances coal gas has been employed.

Navigable Canals in France.—Among the first formed since the Roman æra was that of the Centre or of Charolais, which extended from the Saone to the Loire: its utility will be seen at a glance on the map; the great facility of execution it presented, and consequently its small expense, compared with that of other canals, had long attracted the attention of the government, and it was begun at the commencement of the reign of François I., the epoch of great undertakings. In 1555, Adam de Crapone, who executed the first canals used for irrigation in France, proposed to Henry II. the cutting that of Charolais, and some portion of the work was probably done by this engineer. Under Henry IV. in 1605, it was continued, and the canal of Briare, executed to form a junction of two great rivers, was commenced, when Sully perceived that, if the latter was united to that of Charolais, it would form an important line of communication: the most ancient account of this work in detail is by Charles Bernard, printed in 1613, and dedicated to Jeannin, Minister of Finance under Henry IV. It is there stated, that those who have examined the different projects proposed for joining the two seas in the centre of the kingdom, are agreed that the Lake of Longpendu, equidistant from the Loire and the Saone, which are only 17 or 18 leagues from each other, should be the point of junction; that from this lake issued two rivers, one called Bourbince, which flows into the Loire at Digoin, and the other called the Dheune, which runs into the Saone near Verdun; that the country is sufficiently level; that there are several other lakes and rivulets, by which the two rivers may be abundantly supplied, and that with locks and gates they might be made navigable: but he adds that the Bourbince has 69 feet fall, and the Dheune 75 feet, by which it appears they had not taken the falls, or not accurately, since that of the Bourbince is four times greater, and that of the Dheune nearly six times, than what is stated. He makes from six to seven millions cube metres of earth to be removed, which is nearly the truth. The president Jeannin also caused a detailed examination to be made of the different projects which had been proposed for the canals of Burgundy, and it was determined to execute that of Charolais, in preference to one passing through Dijon; and in 1605, the canal of Briare, which forms a portion of it, was began. In 1612, Descures, Intendant of the river Loire, was sent by the king to examine the project for the junction of the Saone and the Loire, by the means of the rivers Bourbince and Dheune. In his report he shows the possibility of uniting them, and in 1613, the order was given for its commencement, the contract being for 800,000 livres; this was probably for only a portion of it; the project was, however, then abandoned; the Marquis Effiat made a new attempt in 1627; a *procès verbal* was drawn up in 1632 by Gerard, Lieutenant-general of the Charolais, commending its utility; the canal of Briare begun in 1605 had been discontinued; it was re-undertaken in 1638 by order of Cardinal de Richelieu by a number of contractors, who finished it in 1642.

As this canal only united two rivers which flowed into the same sea, and the principal object in view was their junction with the Saone, which flows into the Mediterranean, after having united with the Rhone, the minister in the same year undertook this last project, and appropriated for its cost 950,000 livres; the execution, however, was delayed, probably from the cardinal dying that year; it was renewed in 1655 under Colbert; the intendant and members for Burgundy were charged to examine the project in conjunction with Franchini, a skilful engineer, then employed in the water-works at Versailles. The Sieur Chamois, architect of the king, also assisted. They thought that by rendering the rivers Dheune and Bourbince navigable by means of locks, the purpose would be answered; and they made a design which was approved. In 1665 the king demanded of the States of Burgundy a contribution to defray one-half the expenses of this canal; 600,000 livres was granted, payable in four years, on condition that the king contributed the remainder, without the province being called upon to furnish a larger sum, and that the 600,000 livres should be specially employed to re-imburse the proprietors. The king, at their request, established a duty on salt; the act was published in 1666, in the towns of Dijon, Chalons, Beaune; at the same time Riquet was superintendant for the projected canal of Languedoc; he had already made experiments for bringing water to it, which decided the government on the subject; in 1666, a design was made, and its commencement took place in the same year: the 19th of February, 1667, an order in council was issued, by which the king postponed for a time the canal of Charolais, and authorised the members for Burgundy to employ the sum of 600,000 livres, which had been granted by the states, in establishing manufactories, and partly in liquidating various debts: the canal of Languedoc was completed in 1682. Louis XIV. was desirous to bring the river Eure to Versailles, and commanded the aqueduct of Maintenon to be constructed, which was afterwards abandoned; the expenses incurred by various fortifications preventing this monarch from employing any money in civil improvements. Vauban, however, studied the commercial interests of the kingdom, and seeing that the junction of the Saone and

the Loire was the principal object to which the attention of the government should be directed, in 1689, employed Thomasin, a royal engineer, to examine the projects of the canals proposed in Burgundy; this engineer chiefly directed his attention to the canal of Charolais, and it appears that he took the levels from the Saone to the Loire, but the unfortunate termination of the reign of Louis XIV. was not favourable for such works. Under the Regency, Thomasin was employed in 1719, at the request of Vauban, the nephew of the Marshal, and the members for Burgundy, to examine two other projects; but he finally determined on that of Charolais; he laid down a plan in 1720, and made a report which was approved by Sebastien, member of the academy, and M. Regemort. Many other engineers were at various times employed in surveying and reporting upon this celebrated canal, but it was not till 1783 that letters patent were issued, when Gauthey the engineer, traced out the line, and the work was commenced at the end of April in that year. Companies of pioneers and ground diggers were appointed with clerks of the works over them, and troops assisted in the various operations. Each regiment employed sent at a time 372 men, commanded by ten officers, two of whom were present; each company of twelve men encamped together, and the work was so set out, that a certain quantity was completed every twelve days. The soldiers did not take out the lowest excavations, that being left to stronger men. At the end of every fortnight, a measurement was taken of the work performed by each company, as well as of that which remained unfinished; and a report was made by the surveyor, which was sent to the engineer-in-chief, and submitted in case of dispute to the superior officer of the departments; three hours per day were allowed for meals; a change took place about every fortnight. The troops were employed for three years, and performed work to the amount of 288,400 livres, which was about a tenth of the sum required for the completion. The whole length of the canal was divided into eight and then into ten stations, to each of which a commissioner was attached, who made every day a survey of the works in their divisions, numbered the workmen, planted the piquets for the direction and levels, and took care that the work was executed conformably to the instructions given; they also measured the masonry, and gave in the accounts of the contractors, no new measurement being made till the former one had been paid. They registered the number of workmen employed, and the quantity of work done, and at the end of the month abstracted the whole; the tools, of which they defrayed the expense, were also under their care, those lost being replaced at the cost of the workmen.

The heights of the various locks were set out by the engineer of the canals, who made the drawings for their execution. This celebrated canal, uniting the Loire at the Saone, has its mouth on the first of these rivers at Digoin; it follows the Arroux, then the left bank of the Bourbince, passing through Paray, Genelarde, Ciry, Blanzy, to the Lake of Mont Chanin, where the navigation commences; at some distance from the lake, the canal separates the Lake of Longpendu into two parts, and then passes by the side of the left bank of the Dheune to St. Julien, where it traverses the valley, following the right bank of the Seine, and passing through St. Berain, St. Leger, Dennevis, St. Gilles, and Remigny; it afterwards traverses by Chagny, near the left bank of the Thalie, and passing through Fragnes and Champfergueil, runs into the Saone at Chalons.

The level of the "point de partage" being determined, the line of the canal was set out, by fixing stations on the hills, by means of the spirit level, and the platforms of the locks were determined, the ground between each lock was then accurately levelled, and profiles were drawn on the ground at the distance of every 64 feet, on which the centre of the canal was marked; care being taken to regulate the cuttings, and make them equal to the embankments, agreeable to a table previously constructed, which indicated the depth they were to dig, according as the fall was greater or less; the points were set out on the ground, and rectified so as to avoid too great a bend, and form rather right lines or great curves: the level lines being drawn above or below a lock, a right line was sought about 390 feet in length, which should unite with the two preceding, without making too sharp an angle; in the midst of which was placed the lock, except where the ground offered a proper fall. The ordinary breadth of the canal is 32 feet at the bottom, and 48 feet at the level of the water, the depth being 5 feet; at this level is a set-off, 18 inches in width, on which grows the flag or some other aquatic plant; at 18 inches above the water are two other sets-off, one serving as the towing path, having from 10 to 20 feet of width; the other being 6 feet wide, unless the height exceeded that dimension; in all cases the width was made equal to the height. The fall of its talus in good ground is one and a quarter, on sandy ground one and a half, and where subject to inundation, two. The sets-off have a counter slope of one-forty-eighth to prevent the rain water entering the canal; at the foot of the bank, on the land side, is a ditch of various widths to receive the rain water, which is conducted under the aqueducts traversing the canal; its ordinary width at the bottom is 65 centimetres. In the parts where the canal is backed by steep hills, two ditches are made at some distance apart, one above the other; there is also a ditch at the foot of the talus on the valley side, to receive the water which may filter from the canal, and to prevent cattle from doing injury to the banks. Care was taken

in tracing the canal, that the water was not contained by the made earth to a greater depth than from 2 to 3 feet; when the earth was not of a nature to hold water, the banks were lined with clay 2 feet thick, founded on the solid earth or on layers of shells, or in default of these at 4 feet below the bottom of the canal. This lining rises vertically to the level of the water, at 2 feet distance from the smaller set-off; where the canal is raised above the land, the bottom is lined 2 feet in thickness; the slope of the banks is either sown with hay seeds or turfed. In places where stone was common, the interior of the canal to the level of the water was faced with dry stone, 97 centimetres thick at the summit, giving it a slope of one and a quarter; in such places the canal is only 33 feet wide at the bottom.

Locks all have a fall of 10 feet, except the two guard locks. The length between the gates is 108 feet, the breadth of the lock is 17 feet; at 6 feet above the bottom the facing to the side walls slopes one-sixth; the thickness at the summit is 4 feet, and at the base 9 feet; the height above the bottom is 16 feet, the water rising to within 18 inches of the summit; the side walls are prolonged by winged and return walls; the platform at bottom is formed of a concave arc, 9 inches versed sine, its least thickness being 26 inches. In light soils it is made 3 feet 4 inches; in bad foundations piles were driven, and the platform laid on arches. The wall over which the water is discharged is curved in front to give additional strength to the frame of the gates, its projection is 5 feet 3 inches; under it are the channels through which the water passes to fill the lock; they are 20 inches in diameter, and spring from the middle of the recess in which the gates are placed; they were closed by a wooden plug, which was found inconvenient from the pressure of the atmosphere after the water was lowered, and they were afterwards exchanged for valves, which answered better. The entrance is furnished with a frame, to which a sector is adjusted, closing it perfectly. The sector is moved by a lever, acting on a stone arranged for the purpose at the top of the walls of the lock. The water passes from one lock to the other by channels formed in recesses made in the side walls, so that it cannot in any way injure the platform of the lock. All the masonry of the walls is in freestone 14 inches thick, and generally cramped with iron run with lead. The whole is lined with beton, 8 centimetres thick, to prevent filtration; at the back of all the walls is a coating of clay 28 inches thick.

Gates of the Locks.—The upper gates are 10 feet, and the lower 19 feet in height, so that the top rail rises 18 inches above the ordinary level of the water. The width of the gates is 10 feet 8 inches, the frame 12 inches square, the sills are 9 inches, and the braces 6 by 7 inches; they are covered with deal 2 inches in thickness, and the joints are securely caulked. The hanging posts are cut partly circular, the diameter being 12 inches, and in part bevelled; the framework is morticed and tenoned together; the iron work let into the rails is an inch wide, and half an inch thick; the pivots and socket are of cast iron; the collars at top are 12 inches in diameter, their height 2 feet, and their thickness about an inch; they carry a female screw; the male screw passes into timber secured in the masonry; they are 10 feet long, and an inch thick; the timber under water is pitched, all the other is painted in three oils.

Houses of the Lock-keepers; they are in length 33 feet, and 23 feet wide, outside dimensions; they contain a chamber 9 feet square, a smaller one, and a scullery; in this is a staircase to the garret and cellar; there is also an oven 5 feet in diameter, the cellar is vaulted, and extends under the smaller chamber and scullery, the height of the chamber is 9 feet.

The aqueducts and drains are five in number, and from 3 to 9 feet span; where a greater span is made use of, there are several arches, their breadth varies according to that of the towing path; platforms of timber are laid under all; the height of the piers is at the least 3 feet, and their thickness 20 inches; it is 3 feet 4 inches when the span of the aqueduct is 9 feet. The piers of the arches of 6 feet span are 18 inches thick, and those of the arches of 9 feet are 21 inches; the thickness of the vaults is 18 inches; the facings of the head and wing-walls are of freestone, the rest is of moellon. It was attempted to make the aqueducts pass as near as possibly under the mur de chute, by which one wall was saved; and the canal being there more elevated, it was easier to make the aqueduct pass below it. Experience shows some inconvenience from this arrangement, as it is not possible to construct the mur de chute as it ought to be—to guard against the pressure or weight of water when the lock is full; and to prevent the water filtering through the wall, care was taken, whenever an aqueduct was reconstructed, to place it above the lock, and to separate it entirely.

Bridges.—Those on the great roads are from 25 to 26 feet in width, those for the cross roads are 18 feet 6 inches, their span is everywhere 25 feet, and their height, from the bottom of the canal to the soffite of the vault, is 18 feet. The arches are segments of a circle, one-sixth of their circumference; the thickness of the arch is 2 feet 3 inches on the face, and 2 feet on the interior; the abutments are perpendicular before and behind, their thickness is 6 feet 9 inches, that of the wing-wall is 3 feet 6 inches. The slope for bridges on great roads is one-twenty-fourth, and one-twelfth for those on cross-roads. A quay wall faces the towing path, in breadth 8 or 9 feet between the parapets; the thickness of the wall is 3 feet at the summit, 3 feet 6 inches at the base, and its height is 6 feet. The bridges over the locks are the same height and breadth as the others, but their span is only

17 feet; they prevent the lower gates of the lock from opening in the usual way, and are consequently worked by hooks.

The construction of the bridges is the same as that of the locks, the facings of the walls being of freestone, and the rest moellon rusticated; there are several skew bridges; those for uniting the lands of individuals are for the most part constructed of timber, and are formed over the lock gates; they are composed of three beams, sustained by struts, resting on the gate post, and by a wheel on the side walls; the roadway is 9 feet wide, and formed by planking.

Mouths of the Canal in the Loire and the Saone. — The bed of the Loire being subject to change, the current tends to run from the right bank on which is the lock, and the margins become silted up; to avoid this a stone dyke is constructed on the opposite side of a curvilinear form, for the purpose of directing the current to the mouth of the canal, which is up the stream, and forms an acute angle with the bank; this does not quite answer the purposes intended, and cleaning the entrance of the canal cost annually from 3000 to 4000 francs; in 1811 a coffer-dam was formed in front, which is too high, and tends to produce an undermining at the foot of the opposite banks; this has been prevented by throwing in stones; since the termination of this work, the cleansing costs annually only 300 or 400 francs.

The Mouth of the Saone; the direction of the canal forms a right angle with the bank of the river, and the guard lock, instead of being placed on the bank, is 200 metres distant from it; this interval is constantly dragged to allow a passage for the boats.

This canal unites the Loire to the Saone; from Dijon to the summit level there are thirty locks, rising about 240 feet in 6300 metres; and the length of the summit level is about 3940 metres; the descent to the Saone is by fifty locks, or 400 feet, in a distance of 4700 metres.

The whole length of the canal is 114,322 metres, the length of each lock 100 feet, and breadth 16 feet; the breadth of the canal at top 48 feet, at bottom 30 feet, and the average depth 5 feet 3 inches.

Canal of Languedoc was executed in the reign of Louis XIV. from designs furnished by François Andreossy, an Italian engineer, by whom locks were introduced into France, producing a new epoch in the history of canals, and without which inland navigation never could have been brought to its present state of perfection.

The canal of Languedoc crosses the isthmus which connects Spain with France, and passes through the valley between the Pyrenees and the river Rhone; and it appears that a contract for its completion was made with Paul Riquet on the 14th of October, 1666.

This canal is united with the Garonne below Toulouse, and by means of eight locks passes round the western side of the city, then along the south side of the river Lers, and by thirteen locks it ascends to Villefranche, rising another five locks. From the Garonne to the summit, a distance of nearly 24 miles, it rises by twenty-six locks, a height of 207 feet; the length of the summit level is $3\frac{1}{2}$ miles, after which the canal descends to Castelnaudary, an ancient town occupying the site of Sostomagus, where the great basin is constructed; it soon after falls into the Aude near Carcassonne, having crossed several small streams, and descends by thirty-seven locks. It then traverses the northern side of the Aude and the town of Treves, to the long level near the Olonzac; in this latter course it passes over several streams, and descends by twenty-two locks. Near Olanzac commences the long level, and where it crosses the Cesse, the canal of Narbonne branches off; the canal of Languedoc passes to the north of Capestang by several windings around Mount Ecurene, and then by a tunnel of 281 yards, under a ridge of mountain called Malpas; eight locks afterwards ascend to Fonseranne; the level is then 17 miles in length. After passing these locks it crosses the Orb, near the south side of Bezieres, then the rivers Libron and Herault, and north of Agde winds round to the Lake Bagnes, enters the Lake Thau, and passes through to Cette, on the coast of the Mediterranean; there are five locks during the latter part of its course. The distance from the summit of Naurouse to Cette the port, is $121\frac{1}{4}$ miles, and the fall 621 feet 6 inches.

The length of the canal altogether is 148 miles, and the lake Thau $9\frac{1}{4}$ miles, which being very shallow at the western end, the canal is carried through it for a considerable distance by means of artificial dykes.

This canal cost 14,000,000 livres; the king defrayed one-half, and the province of Languedoc the other. There being some difficulty in making an arrangement with the proprietors of the lands through which it passed, in 1666, the king issued an edict, which states "that Paul Riquet, the undertaker of this work, should take all lands and hereditaments necessary for the construction of the canal, together with all streams, warehouses, banks, roadways, locks, &c. &c." which were to be paid for, after a valuation made by competent persons, named by commissaries appointed by the king. The design was furnished by M. Clerville, the most eminent engineer in France, who had also the direction of the work; the first stone was laid on the 29th July, 1666, at Cette, and in May, 1681, the communication between the two seas was complete, after fifteen years' labour. The canal

is divided into two principal parts, the starting point being near Castelnaudary; one descends towards the Mediterranean, being in length 6,165,000 feet, the other, 1,879,000 feet, descends to the Garonne near Toulouse. After an exact levelling taken between these extreme points, it was found that the point of setting out was 640 feet above the level of the Mediterranean, and 198 feet above the waters of the Garonne. To pass vessels from Cette to the highest point, there are seventy-four locks, with chambers of a little more than 8 feet rise, and twenty-six locks to descend to the same point on the Garonne, which is navigable from Toulouse to the sea. There are altogether one hundred locks; the eight near Beziers form a cascade nearly 1000 feet in length, with a fall of 68 feet equally divided.

There is a circular lock common to three branches of the canal, each having its own gates communicating to a common chamber; there are forty-five aqueducts, and ninety-two road bridges; the canal passes above six of these aqueducts, the finest are those of Repude, Cesse, and Trebes; the thirty-nine others pass under the bed of the canal, for the drainage of the land.

At the surface the canal is 64 feet in breadth, at the bottom, 34 feet, and 6 feet 4 inches deep. The vessels which navigate it are 80 feet long, about 18 feet broad, draw 5 feet 4 inches of water and carry about 100 tons.

Canal of Narbonne is connected with the canal of Languedoc, and was commenced early in 1664; this was extended by Paul Riquet to Beziers. It sets out from the great level near Argelins, leaving the river Cepe on the right, and all the locks upon it are placed at regular distances from each other, which has occasioned a useless expenditure.

Canal of Burgundy, intended to unite the Saone with the Seine, was commenced in 1775, under the direction of Perronet, who has left numerous plans, reports, specifications, and estimates of this great work. The canal commences at Brianon, and the intention was to reach a summit level, which would have been 888 feet above its junction with the river Yonne, and 674 feet above the waters of the Saone. The whole length of the canal was to have been nearly 148 miles; 13 leagues were completed under Napoleon, and the navigation was perfect from the Soane to Pont de Parry, five leagues west of Dijon; on the side of the Yonne, the navigation extended to the town of Ancy-le-Franc.

Canal of Malshum, in Alsace, in length eleven leagues, was executed under the directions of Vauban; it has eleven locks.

Picardy has two principal canals, one called Crozat was completed in 1738.

But the chief canal was that undertaken in 1766, for the purpose of joining the Somme to the Scheldt, between S. Quintin and Cambray, the cost of which was estimated at twenty millions of livres; after repeated alterations in the plans it was completed in 1810; the length is about 32½ miles, and the rise to the summit of the lock of Tronquoi is by five locks, or 33 feet 6 inches; the summit is 13¾ miles in length, including two tunnels, that of Tronquoi 1200 yards, the other called Riqueval 3¼ miles, each of the tunnels 26 feet 3 inches in width; from the end of the latter tunnel to Cambray is fifteen miles, and in that distance there are seventeen locks, each 97 feet in length, and 17 feet in breadth; the whole fall is about 124 feet.

Canal of Loing was completed in 1724, and proceeds from Montargis to the Seine, a distance of 33 miles; this was also executed under Regimorte. It has 21 locks, with a fall of 136 feet 8 inches: it is 44 feet wide at the surface, and 34 feet at the bed, and the depth of water is 5 feet.

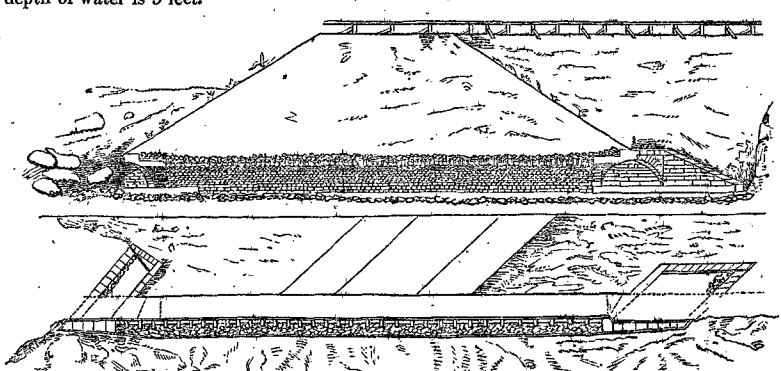


Fig. 259. SKEW ARCH UNDER THE CANAL.

Canal of Briare was begun in 1605, and completed about 37 years afterwards. It commences a mile from Briare on the Loire, and ascends along the banks of the

Trenzi, where there are seven locks, which are supposed to be the first introduced into France, by the engineer Hugues Cromier; they are from 125 feet in length to 165, and in breadth 14 feet 6 inches; their rise varies from 5 feet 4 inches to 14 feet; the breadth of the canal also varies from 25 to 32 feet, the boats draw a little less than 3 feet water.

Canal of Orleans is in length about 45 miles, and has 28 locks, varying from 136 feet to 178 feet in length, and from 5 feet 6 inches to 12 feet 6 inches rise. The breadth of the canal varies from 25 feet to 32 feet at the surface, and the depth is about 4 feet 6 inches. The boats are about 100 feet in length, and nearly 14 in breadth; this work was completed by Regimorte in 1725.

Bridges. The examples left in the southern districts of France by the Romans have been partly described; and after the dismemberment of the western empire scarcely any constructions in stone were commenced till the twelfth century, when necessity produced throughout France and Germany a religious association, which took the name of "Brothers of the Bridge;" they established houses of accommodation for travellers, and built bridges when the rivers were dangerous or difficult to ford. One of the earliest constructed was at Durance, below the ancient Chartreuse at Bonpas, but due consideration not having been given to the water-way, it was soon demolished by the floods to which this river is subject.

Another was built at Avignon about 1177, and the funds were obtained by a pretended miracle, the *procès verbal* of which is still retained in the Town Hall.

The bridge of St. Esprit and of Guillatiere at Lyons, built at the time Pope Innocent IV. inhabited France, and that of the Saut du Rhone, on the road from Vienne to Geneva, were erected by the "Brothers of the Bridge."

During the reigns of Charles VIII., Louis XII., and Francois I., many bridges were constructed, which sustained mansions or buildings of defence, and it became general throughout Europe to adopt this system, particularly in cities, where building sites for the increasing inhabitants could not be obtained.

The Bridge and Chateau of Chenonceaux, commenced by the chamberlain, Thomas Bohier, who died in 1524, is an excellent example of such structures; upon the piers of this bridge the architect Ducerceau constructed a gallery for the Queen Catherine de Medicis, who was charmed with the beauty of the surrounding scenery.

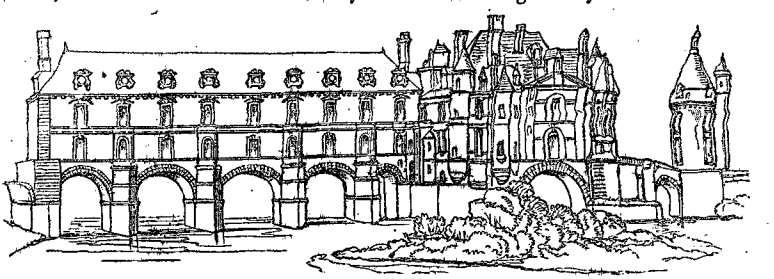


Fig. 260. CHENONCEAUX.

To the great bridge built on the Rhone succeeded some of single arches of great span: those of Ceret, Nions, Castellane, Ville Neuve d'Agen, are from 98 to 164 feet span. The bridge of Vieille Brioude, over the Allier, was the boldest of all; its single arch is above 177 feet. It was built in 1454 at the expense of a lady of that place. In 1545, Cardinal de Tournon constructed a bridge near the town of that name over the torrent of the Daux of a single arch, 160 feet span.

These bridges are built very economically, and have nearly the same character. Their breadth is generally from 13 feet to 16 feet, and few exceed 20 feet. Except those on the Rhone, which are very well constructed, the faces only of the arches are of squared stone, and the voussoirs are very small; the rest is of rubble. The haunches are filled with earth. The piers are always very thick, and above high water their facings only are of stone. The interior is generally filled with earth or sand; they seldom have side walls; some portions of walls, founded upon piles, and attached to the abutments in the line of the heads, generally take their place; the erection of all these bridges may be dated between the thirteenth and sixteenth centuries, and, considering the extreme economy of their construction, it is surprising that they have lasted so long.

Arches of great span, consisting of the segment of a circle, whose height is nearly equal to the diameter, could hardly be erected in towns, where they would encumber the neighbouring houses; in such cases a greater number of arches and less span is far preferable; the most ancient of the kind now remaining is the bridge of Notre Dame at Paris, built in 1507. Until this date the city had only wooden bridges, which were frequently carried away by the ice and inundations, which in 1196 occurred to them all. In 1280, two

more experienced the same fate. In 1412, where the present bridge of Notre Dame now stands, the first of stone was constructed at Paris; this was soon carried away, and houses having been built upon it, the magistrates, through whose bad management the accident had occurred, were condemned to reimburse the proprietors, and not being able to do so, died in prison. The government, fearing a recurrence, sent for Jocondi, of Verona, from Italy, whose construction of the Ponte Corvo had gained him great credit. This architect, who was employed after the death of Bramante, conjointly with Raphael and Julien de Saint Paul at St. Peter's, built the bridge of Notre Dame as it now exists. About sixty years afterwards, the Pont Neuf was begun, and during the interim those of Chatellereau and Toulouse. The breadth of these bridges is very considerable compared with those which preceded them; they appear to have been the first in which flat arches were employed, and to have been built and ornamented with considerable attention.

From the completion of the Pont Neuf, in 1604, to 1656, the Pont St. Michel, Hotel Dieu, Pont au Change, Pont Marie, and La Tournelle, were built. François Blondel gave the designs for the Pont da Saintes in 1666, and Frére Roman, the architect of the bridge of Maestricht, was invited to Paris by Louis XIV. in 1683, to commence one of the piers of the Bridge of the Tuilleries, which was then in progress after forty years' delay; from this period to that of the bridge at Blois, including those built by Mansard at the latter end of the reign of Louis XIV., no considerable work of this kind was undertaken.

Before the time of Louis XIV. there was but little commerce, and transport was mostly effected by mules, which accounts for the narrowness of the bridges, although many were of great length; the foundations are seldom much deeper than the bed of the river, and those of Chalons and Macon are built on piles 5 feet long, and many so constructed have given way; but those that still remain form a very solid mass, occasioned by the hardness of the cement: when required to be enlarged, the starlings may be used as foundations for the new constructions, which is always more economical and safer than building in a new situation.

After the establishment of the Ponts et Chaussées, the designs for bridges were made by the engineers attached to it, and submitted to the examination of a board composed principally of the inspectors-general and some of the divisional inspectors, who, to the knowledge acquired by study, added that which is the fruit of experience. The bridges of the last century are, consequently, much more carefully constructed than those of the preceding, and since this epoch the art has made rapid strides.

The first in order of time is the bridge of Blois, built in 1720, by Pitrou, after the designs of Gabriel, the royal architect and chief engineer of the Ponts et Chaussées, in which Pitrou first proposed his trussed centres for great arches. These arches are elliptical, a form which has since been frequently adopted, as in the bridges of Tours, Moulins, and Saumur, built nearly at the same time over the Loire and the Allier. The completion of the last, in 1764, is the epoch of the introduction of the method of founding by caissoons; in France its application to bridges was due, as we have seen, to Belie, and Cessart was the first to practise it.

The bridge of Neuilly, begun in 1768, by Perronet, united the effect produced by great artists by simple decoration with all that perfection of execution of which this kind of work is capable. A short time after its construction, the arch of a bridge received the form of a segment, whose springing is nearly level with high water. The bridge Fauchard, projected by Voglie, and built by Limay; the bridge of Pesmes, built in 1772, by Bertrand; that of St. Maxence, built in 1784, by Perronet, afforded examples of this kind of construction, which was followed by several other engineers. In 1787, Perronet began the Pont de la Concorde at Paris, in which he reduced the thickness of the piers and arches to less than had ever been done.

The bridges hitherto erected in France may be divided into two sections. The first, as we have seen, comprised those constructed from the twelfth to the end of the fifteenth centuries, all of which are founded on rubble work at but little depth, are extremely narrow, and although some are very long, they have all the traces of great economy: the other comprises the bridges from the beginning of the sixteenth to that of the eighteenth century, when stone bridges were erected in the interior of towns, of greater width and superior construction and decoration. The third section comprises all bridges from the establishment of the Ponts et Chaussées to the present time.

Bridge of Avignon, on the Rhone.—This has been already mentioned as the second bridge built in France after the fall of the Roman empire, and constructed by the association known by the name of "Brothers of the Bridge," in consequence, according to tradition, of a miracle performed by Saint Benezet. It was begun in 1177, and was not entirely completed till 1187, although it was rendered passable in 1185.

At Avignon the Rhone divides and forms an island, and it appears that there were at first two separate bridges over the two arms, in a direction nearly perpendicular to the current of the river; one of five and the other eight arches: they were then united by

eight new arches, built on the island which separated them, in a curved line, so as to unite the two parts already existing; these latter have many sinuosities, although no reason can be assigned for such a deviation from the straight line; the whole number of arches was then twenty-one, of about 180 feet span, and the total length was about 2953 feet.

In 1385, Boniface IX., who resided at Avignon, demolished some arches to ensure his own safety: in 1410, the inhabitants of the town, to rid themselves of a Catalan garrison which Benedict XIII. maintained, blew up the tower which defended the bridge; carelessness in repairing a fallen arch, in 1602, caused the fall of three others, and in 1670 the Rhone having been frozen, the melting of the ice threw down some more, leaving only four entire on the side of Avignon, where the bridge is 21 feet above the soil, no other means of ascent remaining than that afforded by the natural inclination of the ground. The bridge is terminated at each end by two towers; on the Villeneuve side the ascent is more than one in three. Its breadth is only 13 feet between the parapets, the thickness of which is a foot. These circumstances render it doubtful whether carriages ever passed the bridge, mules being formerly the only means for conveying burdens from one place to the other.

On the second pier is a chapel formerly dedicated to St. Nicholas, patron of navigators, one part of which is supported on corbels. The piers are constructed of squared stone as high as the level of the river, and the rest of small rubble work; their upper part and the haunches of the arches are pierced by round apertures. The remaining arches are well preserved; they consist of fine squared stones, 2 feet 10 inches high, and so disposed as to form four separate arcs, which in the first arch present no apparent connection; there is only one in the second, and seven or eight in the third. The heads are a little distance from the centre in the first; some iron cramps remain which united the arcs to each other.

Bridge of La Guillotière over the Rhone, at Lyons, consists of eighteen arches from 26 feet to 105 feet span; its total length is 1870 feet; its water-way 1204 feet. It was built by Pope Innocent IV. during his sojourn at Lyons, partly at his own cost, and partly by granting indulgences to those who concurred in this useful enterprise. An inscription on a tower, since destroyed, preserved the memory of the fact; but on one of the squared stones of the bridge, the following inscription has since been discovered: —

PONTIFEX ANIMARUM FECIT PONTEM PETRANUM.

Pope Innocent having resided at Lyons about 1245, the foundation of the bridge may be assigned to that epoch. But the disparity which exists in the construction of the piers and arches appears to prove that they were built at different, and perhaps very distant, periods; they are all semicircular.

Bridge of St. Esprit. — Its foundation dates from the year 1285, one hundred years after that of Avignon. The first stone was laid by the prior of the monastery of St. Saturnine du Port, and the original documents are found in the archives of the hospital; its construction was effected by the alms which the "Brothers of the Bridge" solicited throughout Christendom. It was completed in 1305; its plan is bent in three directions, and consists of nineteen great arches and six small, which were afterwards constructed under the ascent. The span varies from 80 to 109 feet. The total water-way is 2021 feet; the length 2690 feet.

The piers are more than one-third the span of the arches which they support, and are carried by a foundation of considerable breadth, presumed to be of rubble work. They are surrounded with starlings projecting 9 feet 9 inches, and rising about 6 feet 6 inches above low water; they are formed by double courses of blocks, 6 feet 6 inches long, and 2 feet 3 inches thick, and are further strengthened by jetties, which are maintained with the greatest care. A tax was formerly imposed on salt ascending the Rhone, to defray this expense as well as that of the banks above; in 1790 it yielded 28,000 francs, but it has since been suppressed.

The slope of the jetties being one in one and a half, the surface of the water-way is rendered exceedingly narrow, notwithstanding the great length of the bridge, a serious inconvenience, considering the rapidity of the current in floods, and even at ordinary times. The starlings do not overtop altogether the very high levels; there are holes in the upper part through which, however, the water but seldom passes.

The arches are constructed of squared stone, the voussoirs are disposed so as to form four separate arches, united at every four courses by an intermediary one of only three stones, and their thickness is 5 feet 11 inches. The bridge is very strongly constructed, and the only injury that has hitherto occurred to it are some slight settlements in the first arch on the town side; its breadth is 17 feet 6 inches, but that of the roadway is reduced by the parapets, to 14 feet 11 inches: this is not wide enough to allow of two carriages passing easily, on account of the great length of their axles. From this cause, or from fear of other injury being sustained, the passage was not freely opened to the public; the waggons were unloaded before they were permitted to pass, and the goods transported

on sledges with low wheels, heavy contributions being laid on the merchants by those interested in the continuance of this manœuvre, so injurious to commerce, and who contrived to make the public believe that it was necessary for the preservation of the bridge.

It being, however, perceived that the masonry of the arches was as solid as possible, and that no inconvenience could arise by letting the heaviest waggons proceed, spaces were formed over the piers to permit them to pass easily, the pavement of the bridge was relieved, where it lay immediately over the vaults they were covered by a thick bed of gravel, and the bridge is now perfectly free, without any injury having been sustained.

Bridge of Cêret, on the Tech, was built in 1336, on the road from Perpignan to Pratz de Mouillon. It consists of a single semicircular arch, 147 feet 8 inches span, of squared stone, the remainder is of brick. It is remarkable for the arches in the haunches and abutments, which are from 23 to 26 feet span. This bridge is in good preservation: it is only 12 feet 9 inches wide.

Bridge of Castellane, on the Verdon, near Sisteron; its arch is a segment of a circle, whose chord is 115 feet, and its versed sine 28 feet 9 inches. It was built in 1404, from the produce of indulgences granted by the pope. Its breadth is 6 feet 6 inches, and it is founded on a rock.

Bridge on the Isere consists of four arches, from 70 feet 2 inches to 91 feet 6 inches span. The arches are segments of circles, and the piers which support them are very thick, being 30 feet. The breadth of the bridge is 19 feet 8 inches, it is almost entirely of rubble work.

Bridge of Villeneuve d'Agen on the Lot. This bridge, of about the same date as the preceding, consists of a great semicircular arch 114 feet 9 inches span, two others from 29 feet 6 inches to 32 feet 9 inches, and a smaller one of 5 feet 11 inches. The upper part of the great arch is in a bad state, and tends to separate in several places, but as it is tied together by iron rods uniting two iron arches, one on each side, it may still last for some time.

Bridge of Vieille Brioude on the Allier, situated near the Roman bridge, was built in 1454, by the contractors Grenier and Estone, at the expense of a lady of the place. It consists of a single arch, the segment of a circle, 133 feet 4 inches span, and 70 feet 4 inches versed sine. This is the largest arch existing in France, and probably in Europe; it is 16 feet wide, as are the abutments on which it rests; it is formed of 2 and 3 rows of voussoirs, placed one upon the other without any tie, one is of volcanic stone, and the other of very hard sandstone. The stones are only from 8 to 9 inches thick, by 2 feet 2 inches long. The whole thickness of the circle is 7 feet 5 inches. The bridge is founded on two rocks rising above low water; its great height and its small width, the steepness of the roads cut in the rock by which it is approached, as well as some settlements which indueed fears for its solidity, have caused the road to be turned, and another bridge constructed half a league lower, at Bajace; this was begun in 1750, consisting of three flat arches, rising one third, from 70 feet 3 inches to 76 feet 8 inches span, with abutments 18 feet, and piers 13 feet 8 inches thick, and was finished in 1753. The foundations were on piles. The great arch was 4 feet 9 inches thick, but being, with the exception of the face, constructed of soft stone, which requires a long exposure to the air in order to harden, it cracked directly the centres were removed in the upper part, and fell as far as the twelfth or thirteenth row of voussoirs from the springing, the faces being drawn with it by their connection with the rest of the arch. One of the small arches was, however, finished, the attendant pier serving as an abutment until the following year, when the great arch was reconstructed with better materials, and made 3 feet 3 inches thick.

The soil on which this bridge stands is a compact gravel, into which the piles are driven with difficulty, yet liable to be carried away by the current; it was attempted to prevent this by constructing above a coffer of piles, between which all the gravel was dredged, and its place filled with rubble work. Notwithstanding this precaution the bridge was carried away by a flood, and as the abutments still remain, it is proposed to reconstruct it by raising a single pier, and founding it in a caissoon.

Bridge of Sisteron, on the Durance, was constructed in 1500, and is remarkable from having an arch 85 feet 4 inches span, of an elongated, elliptical form, 57 feet 5 inches in height. It is probable that it was at first pointed, and that the angle at the two arcs was afterwards rounded, which conjecture is further strengthened by the circumstance of the upper and lower parts of the arch being of a different construction.

Bridge of Tournon, on the Daux, built by an Italian engineer in 1545, at the expense of some cardinal. It has one great segmental arch 156 feet 10 inches span, built like the bridge of Vieille Brioude, on rock, and only 16 feet 5 inches wide; it is constructed of pieces of soft, dressed sandstone, except the faces, which are of squared stone. The remaining portion is of rough rubble.

Bridge of Claix, on the Draie, consists of a single arch, the segment of a circle, 150 feet 3 inches span; its breadth is 20 feet 4 inches; it was constructed in 1611, near Grenoble, by the constable Lesdiguières. It is a subject of much admiration with the historians of

Dauphiné, who consider it superior to the Rialto at Venice; before the demolition of the entrance gateway, the following inscription was legible upon it;—

ROMANOS MOLES, PUDORE SUFFUNDO.

Although built in the 17th century, it is placed in the first section, on account of its antiquated construction.

Bridge and Aqueduct of La Crau d'Arles, traverses a marsh, and conveys the water of the canal of Crapone, erected in 1558 by a gentleman of that name. Its length is 2050 feet; the arches are semicircular, and their span is 19 feet 2 inches; the thickness of the piers is 12 feet 9 inches, and the width of the aqueduct 17 feet at the upper part; the faces are slightly inclined.

By the side of the aqueduct is a bridge 32 feet wide, which carries the high road, sustained by arches of the same span as those of the aqueduct; the foundations of the two constructions are supported in the most dangerous places by timber framework.

Bridge of Nôtre Dame at Paris, on the Seine.— A wooden bridge was constructed here in 1413, under Charles VI., who gave it the name of bridge of Nôtre Dame; it was destroyed the 25th of October, 1499, and rebuilt in stone in 1507 by Frère Joconde. It consists of six semicircular arches, from 31 feet 2 inches to 56 feet 8 inches span. The piers are 12 feet 9 inches thick. The plinth which crowns the bridge is sustained by modilions. It is well preserved, and although the stone of Paris is not generally good, this appears to have been well selected, very little decay being perceptible. It was covered with houses, which were demolished a few years ago. Its breadth is 77 feet 5 inches. The pump below one of the arches was constructed by Daniel Jolly, in 1671.

Bridge of Toulouse on the Garonne, was begun in 1543, under Francis I., after the designs of the architect Souffron. It was not finished till 1632, after the Pont Neuf and Pont de Chatelleraut. It has seven elliptical arches, from 47 feet to 113 feet span, symmetrically disposed. The upper part of the pier has openings of a nearly circular form; they are not all placed on the same level, hence the high water little more than reaches those in the great arches; the vaults are 2 feet 8 inches thick. It is of brick, except the archivolts and the starlings, which are of squared stone. Its breadth is 64 feet. The footways are 12 feet 9 inches; the slope of the pavement is about 1 in 26. At the entrance is a triumphal arch, built by Mansard, which supported an equestrian statue of Louis XIII., destroyed in 1793.

Bridge of Chatelleraut, on the Vienne, begun in 1560, under Charles IX., and finished by Sully in 1609. It consists of nine arches, 31 feet 10 inches in span; they are elliptical, except the centre one, which is semicircular, and elevated on piers 8 feet 6 inches high, crowned by a plinth. Judging by the heights to which the floods attain, the water-way appears perfectly proportioned to the volume, to which it gives a passage. The breadth of the bridge is 71 feet 2 inches; on each side are two footways beyond the parapets, 4 feet 6 inches wide, formed by flags sustained on consols 3 feet 3 inches apart.

Bridge of Marche Palu, or Little Bridge at Paris. This was much damaged by the floods of 1649, 1651, and 1659. It was reconstructed in 1695. The 27th April, 1718, two barges of burning hay were carried against it, and most of the houses consumed by fire. It was repaired in 1719, and the houses were not rebuilt. It is situated on the lesser arm of the Seine, next to the bridge of Nôtre Dame, and consists of three semicircular arches from 21 feet to 32 feet span.

Pont Neuf, on the Seine. Henry III. laid the first stone, May 21st 1578; the architect was Androuet du Cerceau. The four piers of the northern part were carried up the same year, but the wars of the League interrupted its progress. It was recommenced in 1602, under Henry IV., by G. Marchand, and partially opened in 1604, but not entirely finished till 1607. The funds were provided by a tax of ten sols on every muid of wine imported into Paris.

The bridge consists of two parts abutting at the extremity of the island of the city, and in the space between stands an equestrian statue of Henry IV. That to the right bank of the Seine has seven semicircular arches from 46 feet to 62 feet 4 four inches span. The first is too high, which renders the ascent of the bridge very steep. The second part consists of five arches, their span varying from 31 feet 3 inches to 48 feet. They are also semicircular, and have small cornes de vache. The width of the bridge is 72 feet, of which 22 feet 3 inches is given to the road-way, 26 feet for the two footpaths, and 4 feet 3 inches for the two parapets. These dimensions are sufficient, although the Pont Neuf is one of the most frequented bridges in Paris. The starlings of the piers are triangular, and rise to the cornice, which is very salient, sustained by large consoles ornamented at their feet with masks of satyrs in very good taste, supposed to be the work of Germain Pilon.

The starlings are surmounted by portions of towers which support the shops erected in 1775 by Soufflot. The bridge was repaired in the course of the same year. The footways were lowered and widened. The pavement between the footways was reinstated in 1821, and the ascent diminished.

In 1608, a timber building called the Samaritaine, containing the pumps for raising water for the service of the Louvre and the Tuileries, under the direction of a Fleming named J. Lintlaër, was placed in the tenth arch on the side of the Quai de l'Ecole Militaire. Henry IV., on this occasion, overcame the obstacles which the municipality of Paris opposed to him from fear of the injury which might result to navigation. The pumps were the first of the kind established in Paris. It was almost entirely reconstructed in 1715 and 1772, and demolished in 1813.

Bridge of St. Michael, at Paris. The first of this name of which we have any account was of timber, and was replaced by one of stone in 1373. This was partly destroyed in 1408, and rebuilt of timber in 1416. Others shared the same fate, the last, with all the houses upon it, being carried away by the thaw of 1616. That which now exists was built in 1618. It consists of four arches, two of 46 feet, and the two others of 32 feet span. The starlings are surmounted by niches crowned by a cornice, except the centre one, on which is still the pedestal that supported the statue of Louis XIII.

This bridge is 112 feet wide, and on each side houses were constructed, which were demolished in 1809, when the approaches were improved.

Bridges of the Hotel Dieu, at Paris; one called St. Charles, and the other au Double, were built about 1634 by the governors of the Hotel Dieu. One consists of two arches, 42 feet span, and the other of two arches 38 feet 4 inches span. They were covered with buildings belonging to the hospital, leaving a passage only 10 feet 8 inches wide for the use of the public.

Bridge of Juvisi, near Paris, is remarkable for a serious error of construction. The piers on which it is built not being thick enough to resist the thrust of the earth, it is retained by eight stone arches built from one wall to another, instead of carrying up one arch lower and larger, which method has been adopted in a similar case, for the causeway at Cravant, where the arch being too large and too high, a second was constructed, the old walls were demolished, and the vacant space filled up, by which the original error was entirely rectified.

Marie's Bridge, at Paris, was built by Christopher Marie, the principal contractor for bridge-building in France, and united the Isle of St. Louis to the other portions of the city. It was begun in 1614, and finished in 1635. In 1658 a flood carried away two arches and the houses upon them. They were rebuilt, first of wood, and then of stone, by means of a toll granted for ten years. The houses were not rebuilt, and the others were demolished in 1789.

The Pont Marie consists of five semicircular arches 45 feet 6 inches to 58 feet 5 inches span. The piers are ornamented like those of St. Michael's Bridge. Its breadth is 77 feet 9 inches.

Bridge of La Tournelle at Paris, also by Christopher Marie, was built of wood in 1614, and carried away by the ice in 1637, and rebuilt of wood; again carried away in 1651, re-constructed of stone, and finished in 1656. It consists of six semicircular arches from 51 feet to 58 feet span, and is ornamented in the same manner as the last-mentioned: the breadth is 53 feet 4 inches.

Bridge of the Exchange, at Paris. A wooden bridge which existed in this place was carried away by the thaw of 1408, again destroyed in 1510, again at a time not exactly known, and a fourth time in 1579. Another thaw damaged it greatly in 1616, and threw down several of the houses built upon it. Lastly, it was burnt in 1621, at the same time with another wooden bridge called Marchand Bridge, only about 30 feet distant from it. The stone one now remaining was begun in 1639, and finished in 1647. It consists of seven semicircular arches, from 35 feet 2 inches to 51 feet 6 inches span. Its breadth is 107 feet: there were two rows of houses demolished in 1788. This is the largest bridge in Paris.

Bridge of Maestricht, on the Meuse, built in 1683, by Frère Romain, a Dominican friar; it consists of eight stone arches, from 39 feet to 44 feet span, and a timber platform, which, in case of siege, could be easily removed. The arches are ornamented with archivolts. The plan of the starlings is an equilateral triangle on one side, and a half octagon on the other. The salient angle being too sharp was destroyed by ice: it has been repaired, and the angle rounded off.

Bridge of the Tuilleries, or royal bridge. A wooden bridge was constructed in 1632 by a contractor named Barbier, in the direction of the Rue de Beaune. This was burnt in 1656, as well as the Machine de Jolly, which raised water from the Seine. Cardinal Mazarine proposed to pay for its construction by means of a lottery, but this could not be effected, and it was rebuilt of timber, which was destroyed by a flood the 20th of February, 1684, and the foundations of that which now exists were laid the 25th of October of the following year. Louvois had just succeeded Colbert as superintendent of buildings.

The designs were made by Mansard, and the construction carried on by Gabriel. The foundation of the first pier on the Tuilleries' side presenting some difficulties, on account of the bad quality of the soil, Frère Romain was sent for from Maestricht, who was, we

believe, the first to use dredging machines, which he applied in this instance to prepare the earth on which the pier was to be built, and sunk a large barge filled with stones, surrounding it with piles and a jetty. A kind of chest was then sunk containing courses of stone cramped together, which were rendered more secure by long guarding piles, and the space between the walls was filled with rubble and puzzolana, then used for the first time in Paris.

The foundation was loaded by a weight much greater than what it would have to sustain after the bridge was built, and as at the end of six months' trial it only indicated a compression of three-fourths of an inch, which was attributed to the contraction of the mortar, the pier and two collateral arches were carried up in perfect security. In the former were deposited all the inscriptions and medals.

The bridge consists of five elliptical arches, from 68 feet 9 inches to 77 feet 2 inches span: the breadth is 55 feet 9 inches: the thickness of the arches 5 feet 6 inches. They are arranged with more regularity than in any of the preceding bridges of Paris. The two entrances are widened by forming over half of the last arches recesses, supported on trompes, which greatly facilitates the passage of carriages. The river is narrower at this point than at any other, consequently the current has a greatet depth and rapidity, and much of the bed is every year carried away, to prevent the evil results of which, materials are continually thrown in.

The cost of this erection was 742,000 livres.

Bridge of Blois, on the Loire, was the first built after the establishment of the Ponts et Chaussées. It was begun in 1720 by Pitrou on Gabriel's designs. It consists of 11 elliptical arches, from 54 feet 9 inches to 86 feet 4 inches span. The starlings are in the shape of an equilateral triangle up the stream, and a semi-hexagon down it. The three first piers are 16 feet thick, the two centre 17 feet, and the two others 24 feet 6 inches; and these doubtless were intended for abutments in case some of the arches should be carried away. The other piers, however, appear thick enough to resist the pressure. The slope of the paving is about 1 in 200: it is too great: the water rises to the key of the lesser arches, while in the middle arches a considerable space remains useless. This bridge appearing after its construction not to give sufficient water-way to the Loire, a new channel for the water has been opened above.

Bridge of Compeigne, on the Oise, was built in 1733 by Hupeau, engineer of the Ponts et Chaussées. It consists of three elliptical arches rising one-third: two of them are 70 feet 3 inches in span, and the other 76 feet 9 inches. It appears that in this bridge starlings were used for the first time, whose plan is a triangle formed by two arcs, each equal to one-sixth of the circumference.

Bridge of Têtes, on the Durance, was built, in 1732, by Henriana, a military engineer, to connect the road between Brançon and Têtes. The arch is very nearly semicircular, and has a span of 124 feet 8 inches. The voussoirs are alternately 4 feet 9 inches and 5 feet 4 inches in length. The breadth in the middle is only 16 feet; but it is widened towards the entrance, and a considerable talus is given to the abutments, which no doubt adds to the stability of the edifice; and we have many other examples, still it appears more advantageously applied to timber than to stone bridges.

Bridge of Cravant, on the Yonne. This was built by M. Advyné in 1760, and has three elliptical arches, rising a third, from 57 feet 5 inches to 64 feet span. The thickness of the piers is 12 feet 9 inches.

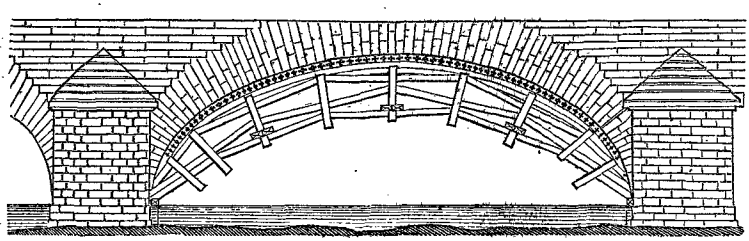


Fig. 261. CRAVANT BRIDGE.

Bridge of Charmes on the Moselle, built in 1740, consists of ten semicircular arches 64 feet, and two lesser semicircular arches 34 feet 2 inches span. As the stream does not rise higher than 7 feet 5 inches, the water-way is evidently too great. The lesser arches are separated from the rest of the bridge by massive piers 128 feet thick. The starlings are of squared stone, but the arches and spandrils of rusticated rubble.

Bridge of Toul, on the Moselle, built in 1754 by Gourdain, has seven elliptical arches from 48 feet to 54 feet 6 inches span: it is constructed of squared stone.

Bridge of Trilport, on the Maine, projected and executed by M. Chezy, who began it in 1756 and finished it in 1760; the outlay was 489,000 livres; it consists of three elliptical arches; the centre is 81 feet span, the two others 76 feet 9 inches. The thickness of the piers is 7 feet 5 inches, that of the abutments 19 feet 2 inches. The breadth of the bridge is 32 feet. The arches are skewed, their axes making an angle of 72 degrees with that of the bridge; the foundations are on piles and a timber framework, and the water was pumped out by means of a vertical chain pump and a bucket-wheel driven by the current.

To avoid the acute angles which the joints of the voussoirs would have formed with the bridge, from the skewing of the arches, Chezy introduced half-voussoirs or cornes de vache on each side of the bridge, the breadth of which is 5 feet 3 inches at the springing, gradually diminishing to nothing at the summit of the arch; the half-voussoir is comprised between the plane of the head and another vertical plane. The surface of the intrados is described by a horizontal generator, perpendicular to the plane of the head, passing through the intersection of the vertical plane just mentioned, with the vault of the arch. The planes of the joint of the voussoir pass through the intersections of the planes of the joint of the vault with this same vertical plane, and through the generators of the voussoirs. The details and working drawings of these arches are given in a treatise by M. Bruyère, entitled, "Etudes relative à l'Art de Construction."

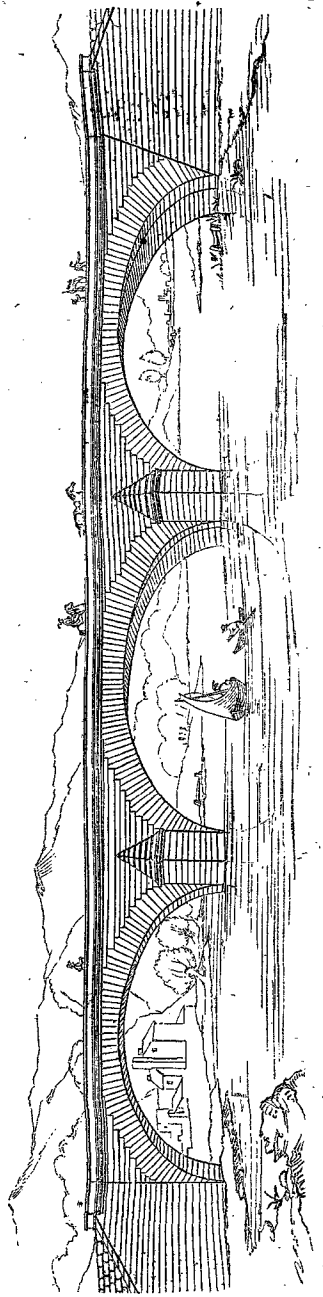
The bridge of Trilport was destroyed in 1815, the middle arch was removed, and the two piers yielded to the pressure of the lateral arches.

Bridge of Port de Piles, on the Creuse, erected in 1747 by Bayeux: it consists of three elliptical arches rising one-third, and from 99 feet to 103 feet 8 inches span. The voussoirs were laid on beds of mortar beaten with a mallet, and in their joints, to the sixth course from the key-stone, long and wide wooden wedges were introduced, by means of which the compression was so regulated that when the centres were removed, the great arch sank only an inch, and the two others rather less.

Bridge of the Pope, on the Erieux, constructed in 1756 by Pitot, consisting of seven arches nearly semicircular, 48 feet 6 inches span. It is of squared stone; the abutments are founded on a rock, but all the piers are built on piles. A general framework was constructed by driving two rows of piles capped both up and down the stream.

Bridge of Orleans, on the Loire, begun in 1751 from designs by M. Hupeau. The work was carried on under his orders by Soyer, and was finished in 1760. Pitrou had made a nearly similar design, except that the situation was a little different, and the radius of the arches at the springing was greater, which tended to increase the water-way.

It consists of nine elliptical arches rising a fourth, from 98 feet 1 inch to 106 feet 7 inches in span. The piers are from 6 feet 3 inches to 10 feet 7 inches high, and from 18 feet 2 inches



BRIDGE OF TRILPORT ON THE MAINE.

Fig. 262.

to 19 feet 2 inches thick: the abutments are 23 feet 5 inches thick; the middle arch is 7 feet, and that which joins the abutments 5 feet 10 inches thick. The breadth of the bridge is 49 feet. The plan of the starlings is formed by two arcs, one-sixth of a circle up the stream, and a semicircle down it.

The foundations are established on piles carrying a framework and platform of carpentry: the soil is a bed of sand from 4 feet to 13 feet in thickness, which covers irregular layers of marl and tufa. A foundation of this kind being very permeable to water, the pumping was attended with great difficulties. In the sides of the cofferdams, with which the abutment and piers were successively surrounded, several springs worked, which it was impossible to exhaust. They were at length enclosed in cisterns, in which the water was allowed to rise and round which a cofferdam was constructed with planks and clay: the nature of the soil also rendered pile-driving in some places very irregular; it often occurred that by the side of a pile which would only drive 6 feet into the tufa, another would go 16 feet, according to the nature of the beds they traversed.

The arches were constructed on trussed centres, which being found too weak were strengthened by adding some pieces in the upper part, but after their completion, a settlement was perceptible in the seventh pier from the town, and a load of rubble weighing $1\frac{1}{4}$ tons was added to the two arches which it supported; the pier gradually sank 1 foot 7 inches, and the weight remained on it for five months afterwards. The pier and haunches were then relieved by small vaults in the upper part, which do not appear on the outside, being concealed by the facings. The same precaution was taken for the fifth, sixth, and seventh piers. The two arches adjoining the seventh pier have not experienced any accident and have only a slight irregular curvature, hardly perceptible. The only reason which can be assigned for the settlement is, that under the bed of tufa there was probably a soil, so light, that it only acquired sufficient consistence by the weight and compression to which it was subjected.

The year after the construction of the bridge a sinking of the earth under the tufa took place under three of the arches and some of the starlings, to the depth of 2 feet 2 inches, and it was deemed necessary to drive two rows of piles close to each other, and 12 feet 9 inches apart, the whole length of the bridge, and 6 feet 6 inches below the starlings; they were cut off 3 feet 3 inches below the surface, and the space between was filled with rubble. All the other portions that had settled were treated in the same manner.

The cost of Hupeau's design amounted to 2,084,000 livres, and the additional outlay was 587,000 livres. It was opened in 1768 by Perronet, who has published the details of the construction.

Bridge of Saumur, on the Loire. The designs were made by M. de Voglia, the engineer-in-chief, and presented to the Ponts et Chaussées in 1753. The works were begun in 1756, and finished in 1764, under the superintendence of De Cessart.

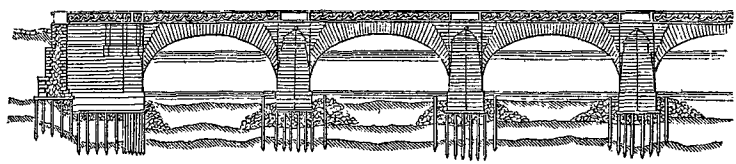


Fig. 263. SAUMUR.

This bridge consists of twelve elliptical arches of 64 feet span, rising a third. The piers are 12 feet 9 inches thick; some are 17 feet high from the springing.

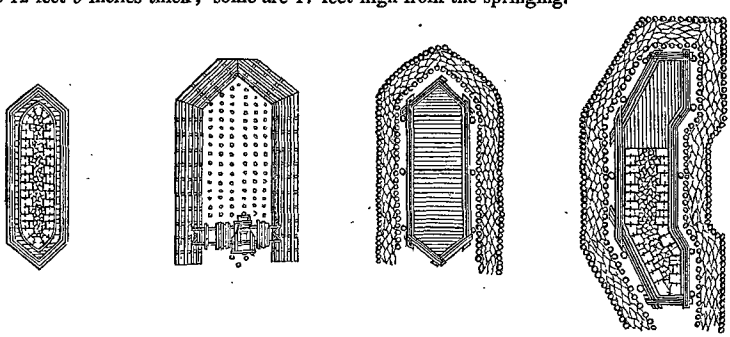


Fig. 264. PLAN OF PIERS, SAUMUR.

The first soundings indicated a bed of gravel from 13 to 16 feet thick, and the length of the piles was fixed at from 26 to 30 feet. The foundations of an abutment and the adjoining pier were first laid, but the exhaustion of the water was so difficult, that only one pier could be finished in the first season, and the piles were cut off 4 feet 4 inches below the surface. The abutment was finished the next season, and the piles cut off 4 feet 4 inches below low water.

It being found impossible to establish cofferdams for the piers in the middle of the river, a proposal was made to adopt the method indicated by Belidor, which consisted in cutting off the piles under water, and sinking a platform loaded with masonry, by means of several screws firmly fixed. M. de Cessart invented a saw to perform this operation, but more careful consideration induced the engineers to use the caissoons, which Labelye had just employed at Westminster Bridge, and which were merely placed on the ground carefully levelled. The bottom of these caissoons was composed of pieces from 10 to 11 inches thick, which could rest on the piles throughout; the sides were moveable, and might be adapted to a new bottom after sinking the former one.

All the other piers and the second abutment were founded in this manner. The piles of the second pier were cut off 7 feet 6 inches, and some 12 feet 9 inches below the surface. Care was taken to dredge the sand between the piles as much as possible, and to fill up the intermediate space with rubble, the upper surface of which was levelled 6 inches below the heads of the piles, so as not to affect the placing of the caissoons.

The piles were driven by a ram moved by a wheel adapted to a horizontal axle; this saved one-half the expense and number of men. The saw for cutting off the heads, which has since been employed in several other places, was completely successful. The invention of this machine may be considered as a very important era in the art of building under water, and one of the most powerful methods at the disposal of constructors to overcome the difficulties which nature opposes to them; it has sometimes cut off twenty-two piles in a day.

Founding the piers at the bridge of Saumur, by means of a caissoon, by De Cessart in the year 1757, was thus accomplished.

The bottom of the caissoon was 48 feet in length, and 20 feet in width, from outside to outside.

The ends were in the form of an isosceles triangle, two sides of which were 13 feet 3 inches.

The outside timber of the frame-work was 18 by 16 inches, scarfed in their length, in the manner termed *traits de Jupiter*, and rebated on the inside edge to a sufficient depth to receive the timbers which crossed from side to side, and were dovetailed at every 3 feet, the

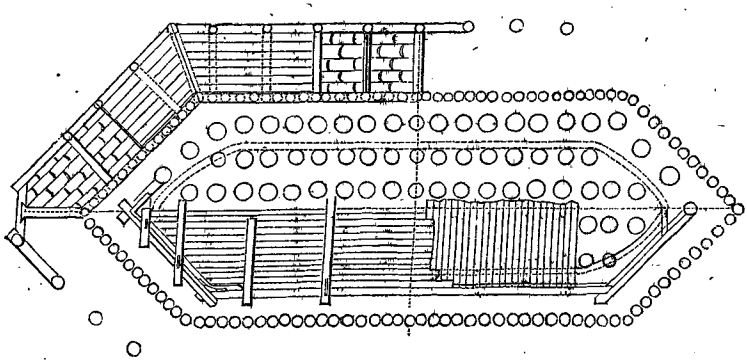


Fig. 265. SAUMUR PIERS.

others between them being laid with square edges; they were secured by wooden pins an inch in thickness, not driven entirely through, in order that the bottom of the caissoon should present no inequality to the heads of the piles on which it was to rest. To fasten them, however, more effectually, a wedge was driven into the points of the pins previous to their being inserted, which forced them upwards, and formed beneath a second head, rendering their withdrawal almost impossible.

After the first planks were laid and pinned down, another piece, 10 inches in width, and 8 inches in height, was spiked over their ends and united to the main timber by iron bolts, 15 lines in diameter, at every 3 feet; on this was laid another longitudinal timber, 12 inches high and 8 inches in width, bolted through the planks, and laterally through the main timbers: the space between these outer timbers was then covered with planks.

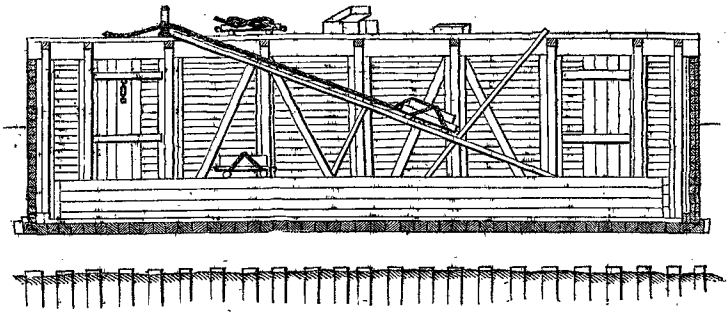


Fig. 266. SECTION OF THE CASSOON.

4 inches thick, laid longitudinally, and crossing at right angles those previously laid; thus the bottom became 14 inches thick, and the superficial area of the base 1160 square feet.

The height of the sides was 16 feet above the bottom, and composed of 24 squared timbers, the scantling of which was 9 by 6 inches, laid on edge; these were of oak, and the length of each course was 72 feet; at the angles they were lapped one over the other, each two courses were alternately pinned together, making one solid mass.

To strengthen the angles, the timbers were doubled, pieces 4 inches in thickness being placed vertically; one in the angles, 18 inches in width, between two others 12 inches in

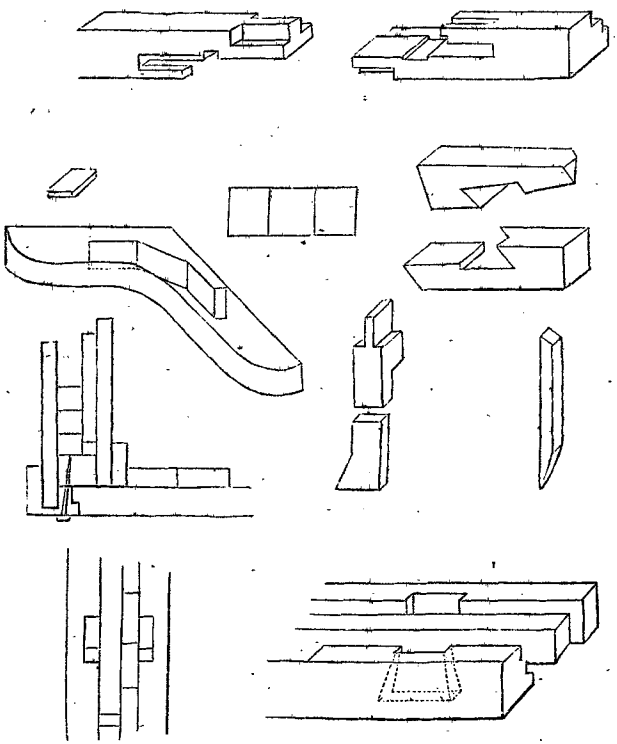


Fig. 267. JOINTS OF THE CARPENTRY OF THE CAISSOON.

width, well pinned into the outer timbers, the wedge being driven into the heads of the pins to render them more secure.

In addition, there were three knees or curved pieces, 8 feet long and 8 inches square, nicely fitted, and pinned very securely with oak pins.

Within the caissoon were placed perpendicularly other planks at the ends, 4 inches in thickness, and 12 inches in width, pinned with great care; between these and the angle ties were five others, at equal distances apart, sustained by diagonal sheets, all securely pinned.

For closing the joints the outer edges of

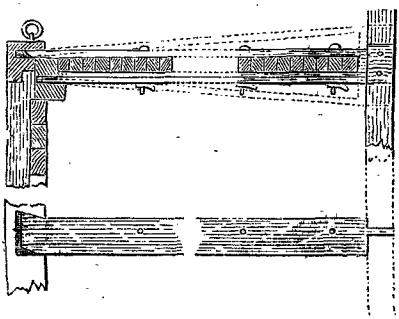


Fig. 268. SIDES OF CAISSOON.

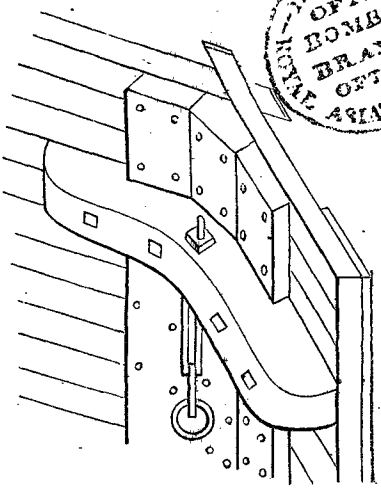


Fig. 269. CARPENTRY OF CAISSOON.

the timbers were all chamfered, and moss of the oak was forced into them by means of chisels with rounded edges, driven by iron hammers till it became very hard, and effectually closed the joints. Oak laths soaked in water, an inch in width, rounded on one side and flat on the other, were nailed over the joint of moss, care being taken to drive the nails alternately above and below the joint; this manner of caulking with moss had been previously used with success for all the large barges which navigated the Loire.

To attach the upright sides to the bottom of the platform of the caissoon, De Cessart made use of a very simple contrivance, so that by drawing a wedge the whole might be released at one time. We have observed that the sides were composed of layers or courses of squared timbers; in the inside and outside of these were others placed perpendicularly, and dovetailed into the sides of the main timbers of the lower platform, which dovetails were so cut, that they allowed the timber to be wedged home by an upright piece placed along their sides, and at the bottom a void of 2 inches in depth was left, which, after the screw which

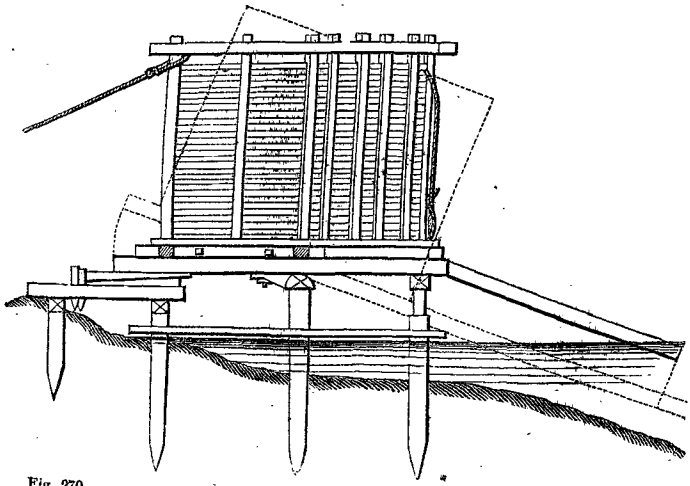


Fig. 270. CAISSOON.

held the main upright in its place was withdrawn, permitted it to descend, and the wedge piece by its side to be drawn up; when this was done the whole side was easily removed.

This caissoon was constructed in a convenient situation, and commenced by driving three parallel rows of piles 3 feet from centre to centre, forming twenty-four piles, united by cross pieces 22 feet in length; the first row was cut off level with the water line, the second and third 3 feet higher, in order that the inclined plane might facilitate the floating of the caissoon. The whole was made level to receive the platform by blocking up with timbers, 30 feet in length, and of a scantling 15 by 12 inches. In the middle was a projecting bracket and other contrivances, so that when the bottom of the caissoon was raised to an angle of 20 degrees, it would slide easily into the water.

In laying out the bottom, care was taken to place its centre of gravity 6 inches within on the land side, and after the caissoon was constructed, it was filled with water by means of a pump, to prove the caulking.

To fix the upright timbers which were attached to the horizontal layers that formed the sides of the caissoon, four iron bolts, 20 inches in length and an inch in diameter, were passed through them, with their heads on the outside and the nuts within, that they might be easily unscrewed; these were well caulked round with moss to keep the water from pene-

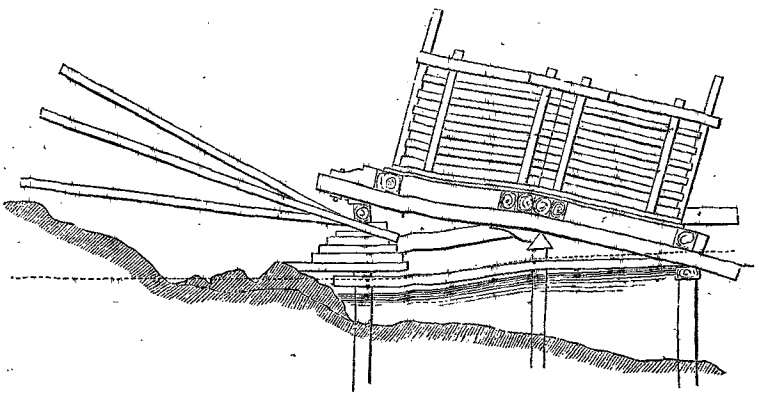


Fig. 271. CAISSOON.

trating, and eight chains were attached to them to facilitate their drawing. To prevent the caissoon from collapsing when placed in the water, five diagonal struts were introduced, which could be easily moved: after all was prepared, the wedges towards the land were withdrawn, and the centre of gravity being 6 inches nearer that side, an inclination to move was given to it; sixteen men at eight jacks raised it a trifle, and then allowed it to slide gently towards the river; when afloat it drew 24 inches of water; the bottom was forced up about 3 inches in the centre for every 1000 feet superficial of base, 3½ inches for 2080 feet, and 5 inches for 5084 feet. It was towed to its position on the Loire by six rowers, and before the heads of the piles were cut off, the lower course of masonry was commenced, 14 inches in thickness, over the lines previously drawn for the position of each stone. After this it was found that the caissoon drew 41 inches of water, and remained perfectly level. An inclined plane was formed of two pieces of timber, on which ran a small carriage, that brought down the blocks of stone, and facilitated the operation of the masons.

When the heads of the piles were all cut off, the caissoon was towed to its place, every precaution being taken to moor it in its exact situation; the second course of stone was then laid, 20 inches in height, formed of 30 blocks; the caissoon then drew 61 inches of water, its position was again verified by stretching a piece of timber across the intended span, and when half the third course was laid, it was settled on the heads of 116 piles, driven to receive it; a verification was then made that it had taken up its exact distance from the piers already constructed on the land.

The fourth, fifth, sixth, and seventh courses of stone were then laid and cramped, and in the eighth course, which formed the springing of the arches, were introduced three mooring rings on each side, tied at their ends by irons 14 feet in length.

All the masonry being completed, the joints well dressed, and covered with powdered lime and fine sand, which hardens in water like puzzolana, the sides of the caissoon were

removed by first taking out the irons at the ends, cables were attached to the rings of the chains, the bolts which held the upright pieces were withdrawn, and the stays inside were removed; the water then entered; the upright timbers, which have been described as dove-tailed at their ends, were driven downwards, and the wedges at their side being released, were drawn up by hand; these were all taken out in succession, and the sides drawn out by means of three crabs placed in a barge, after which they were towed away to be applied to the bottom of another caissoon for the next piers.

To relieve the centres after the arches were turned, De Cessart adopted the plan of cutting away a portion of the ends of the braces; he removed the wood by making as it were three mortices, and leaving the whole centre supported upon two tenons at its ends, 2 inches in width only; these were afterwards cut away, and the whole dropped in a body.

Bridge of Tours, on the Loire, begun 1755 by Bayeux, is the longest bridge in France, except those of St. Esprit and La Guillotiere, over the Rhone at Lyons.

It was finished in 1762, and consists of fifteen elliptical arches, rising a third, and 80 feet span. The piers are 16 feet thick; the breadth of the bridge is 48 feet; it was founded partly by cofferdams, and partly by caissoons; the length and water-way appear great when compared with the neighbouring bridges; several accidents have nevertheless occurred.

The bottom is a sand bank from 6 to 10 feet thick, under which, and from 19 to 23 feet below low water, is a bed of tufa, in which the piles penetrate about a foot. This foundation appeared sufficiently secure; the piles of one pier have, however, yielded to the superincumbent weight, and it has sunk about 3 feet, and gone over about as much. The arches were demolished, and the pier removed, as well as another construction on the old foundation; this accident is attributed to the bad quality of the timber of the piles, which had remained a long time underground, and were partly rotten.

A thaw then occasioned the sinking of three other piers, the ice formed a kind of bar above the bridge, and the water running rapidly under the arches on one side only carried away the sand between the piles, and laid them bare, and four arches fell in. The reconstruction of the piers was very difficult, the ruins of the first pier were removed with great labour and expense, and the foundations were consolidated and rendered secure; the second pier was still more difficult, the piles having gone over 3 feet on one side, and it was proposed to suppress the three last arches, which would have given a greater water-way than was necessary; this plan was therefore not adopted, and a method was suggested for establishing a cofferdam on the platform of a caissoon, which projected 4 feet 3 inches beyond the masonry, and the latter faces were thus restored. The interior was then to be emptied, and the courses and bottom would be easily removed, it being impossible to arrange a cofferdam in the usual manner, from the great depth, and the ruins of the arches.

This method did not entirely succeed, because the piles had yielded unequally; those on the outside having resisted more than the others, the bottom was broken and the pier had passed through it. These injuries rendered the total exhaustion of the cofferdam impossible; the remaining courses were raised piecemeal by multiplying the machines and pumps, and the bottom of the caissoon being entirely destroyed, it was removed by thirty-six chains attached to different machines, worked by ninety-six men, who raised about 91½ tons at once; it was brought ashore by 150 casks and two boats.

Bridge of Moulins, on the Allier, was begun in 1756, and finished in 1764, under the direction of M. de Regemorte, and consists of 13 elliptical arches, 64 feet span. The piers are 11 feet 8 inches thick; the breadth is 42 feet 8 inches. The construction of this bridge was very difficult; three bridges had been erected in the same situation in 35 years; two, of stone, had been successively carried away. The last was by Mansard, it consisted of three great elliptical arches supported by thick piers, which only gave a water-way of 377 feet. The length was 830 feet. The fall of these bridges was attributable both to defects in their construction and want of width, a circumstance which the nature of the bottom rendered very dangerous. The bottom is a coarse sand of great depth, into which it is difficult to force piles of from 10 to 12 feet, although the floods frequently tear it up to a depth of 16 or 20 feet.

M. de Regemorte perceived the necessity for increasing the water-way considerably, in order to diminish the velocity of the current, and the sequel has proved that what he gave it was far from being too much. In 1790 the water rose to within 3 feet of the crown of the arch, and it was thought that if the right bank had not given way, it would have run some risk. The increase of width did not remove all fear for the safety of the bridge; it was thought that the least obstacle in one arch might occasion the soil to be carried away from under the others; to avoid this a framework was constructed under the bridge, 6 feet 6 inches thick, having the upper surface 3 feet 3 inches below the level of the water: the breadth is 111 feet 6 inches. This precaution set all anxiety at rest. There are few cases where the arrangements have been made so perfectly in accordance with the natural circumstances of the place, or have been worked out in so intelligent a manner. The details of the construction have been published by M. de Regemorte.

Aqueduct of Montpellier, is one of the finest works of the kind in France, and conducts water from the sources of St. Clement and Boulidou to the town of Montpellier. It was built in 13 years by Pitou.

There are two tiers of arches, the lower is 70 in number, their span is 27 feet 8 inches, the thickness of the piers 12 feet 3 inches. Those of the upper tier are only 9 feet. The greatest height of the aqueduct is 92 feet. It is entirely constructed of squared stone; one of its terminations is in the Place de Peyrou, which it traverses on three arches, where there is a reservoir. The total length is 3215 feet.

Aqueduct of Carpentras, on the Auzon, has 33 semicircular arches, 38 feet 4 inches span, and 12 lesser arches of 25 feet 7 inches, without comprising a segmental arch of 76 feet 9 inches, on which it crosses the Auson. The thickness of the piers is 12 feet 9 inches. Its width is 7 feet 3 inches above and 17 feet below; the greatest height is 82 feet, and the total length 2560 feet.

Bridge of Dole, on the Doubs, begun in 1760, and finished in 1764 by Guéret, consists of 11 elliptical arches rising a third, from 52 to 62 feet in span. The piers are from 10 feet 8 inches to 11 feet 6 inches in thickness. Their foundations, 7 feet 6 inches below the water, are supported by little piles about 13 feet long. The facings are of squared stone, and the bridge appears to have been carefully built.

A sort of false framework was constructed below bridge, and some jetties made round the piers; two, however, sunk, which has occasioned the fall of the corresponding arches. The piles which supported them had been entirely deprived of the materials which retained them, and it had been thought sufficient to place jetties round the piers, without filling up the void formed in the interior of the foundation.

Bridge of Mantes, on the Seine, where the river is divided into two principal branches, each about 360 feet wide, and one lesser branch: the old bridge, called that of Limay, was

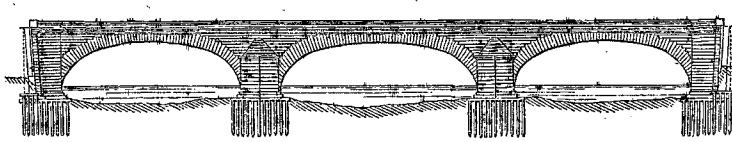


Fig. 272. MANTES.

constructed on the first of these; the second, called Fayol, from the name of the engineer, is composed of thirteen arches, comprising one for the towage; there is also a third, with the same number of arches, below which a new bridge was commenced.

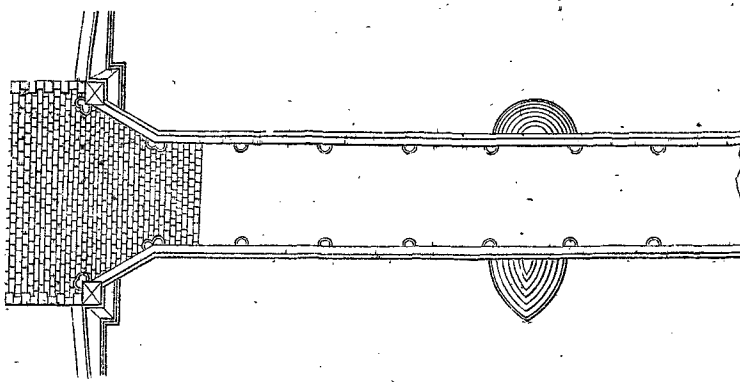


Fig. 273. PLAN OF MANTES BRIDGE.

The stone employed was brought from the quarries of Saillancourt, Cherance and Veteiul, all of which were of excellent quality. In Perronet's work is shown the construction of the centres, and the methods adopted to supply the various material to the workmen, which are novel and interesting.

The cofferdam was formed in a similar manner to that constructed at Neuilly; the piles were shod with iron and driven with heavy rams, some with a force of half a ton; and after the whole were placed, the dragging commenced, and was continued until all the mud and sand were removed; the machine used being that contrived

by M. Regemorte for the same purpose at the bridge of Moulins. The space between the piles was then filled with clay, and, when water-tight, the pumping out was commenced, and the whole of the vast interior rendered dry: pumps and chapelets worked by men, and an undershot-wheel, being constantly in use for this purpose; the whole was under the directions of M. Hupeau, who made the designs and commenced the foundations in 1757, and was finished by M. Perronet in 1765; it consists of three elliptical arches, 115 and 128 feet in span. Their springings are 3 feet 3 inches below the surface, and the platform of the foundations 6 feet 6 inches; the height of the middle arches 37 feet 3 inches, and of those at the two sides 35 feet 8 inches. The piers are 25 feet 7 inches, and the abutments 28 feet 9 inches; the width is 35 feet 5 inches.

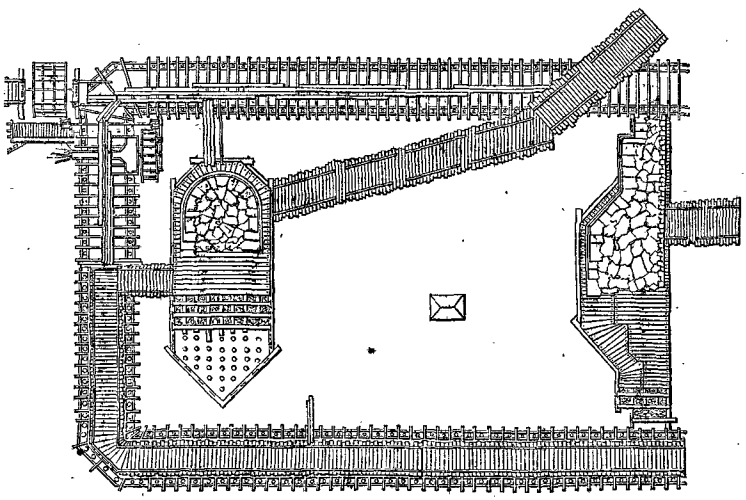


Fig. 274. COFFERDAM AT MANTES.

In constructing the arches of this bridge, they commenced by one of the side arches, which was almost finished, when there were only ten courses of voussoirs on the middle arch. The inequality of pressure resulting from this on the intermediate pier thrust it in a horizontal direction. The piles took a slight inclination, and, although the voussoirs of the great arch were placed with the greatest possible celerity, the motion was not stopped till the pier had moved 4¾ inches; the arch was, however, continued, and, to prevent the effect of pressure on the other pier, care was taken to preserve the distance from the centre by ties composed of pieces scarfed together. This precaution succeeded perfectly, and after putting in the key-stones, the first pier was carried back 2¼ inches towards its proper position. The details of the construction have been published by M. Perronet.

Bridge of Bord, on the Oeil, built in 1764 by M. Leclerc, is on the road from Moulins to Autun. It consists of a single arch 69 feet 3 inches span. All the facings are of squared stone, and the work is very good.

Bridge of Nogent, on the Seine, built between 1766 and 1769, by M. Perronet, consists of one elliptical arch, 96 feet in span, 29 feet 9 high from the springing to the key. The thickness of the abutments is 19 feet, they have shoulders and terrace walls. The arch is of very hard sandstone, and its thickness is from 4 feet 3 inches to 5 feet 2 inches.

The bridge of Nogent has been the subject of an interesting experiment on the motion and rupture of arches. Before the centres were removed, a portion of the masonry of the haunches had been constructed, which partly prevented the joints of the voussoirs, which had opened during the progress of the work, from closing as they generally do; added to this, the centres were struck immediately after the arch was finished, which increased the settlement; these different circumstances rendered the points where the acting parts of the vault separate from the resisting parts very visible, and particular arrangements have been made with the view of ascertaining them exactly.

Bridge of Albias, on the Aveyron. This was built in 1770 by M. Boesnier. It consists of three elliptical arches 76 feet 9 inches and 83 feet in span. Its width is 39 feet.

Bridge of Sorges, on the Anthion, constructed by M. Regemorte; it consists of 7 arches 19 feet 3 inches in span. Gates are attached to them by means of which the water may be

entirely shut out. The object of this is to prevent the inundation of the Loire, which covered an extensive country, and made the Anthion flow back to a great height.

Bridge of Carbonne, on the Garonne, constructed in 1770 by M. Saget. It consists of three equal elliptical arches rising a third, 102 feet in span. The vaults are extradossed, and with the starlings are of squared stone, the rest is of brick. The width is 25 feet 7 inches.

Bridge of Montignac, on the Vézère, begun in 1766 and finished in 1772 by Tardif. It has two semicircular arches, 42 feet 8 inches in span, and one elliptical of 66 feet. The abutments and one pier are founded on a rock. The other pier is supported on piles.

Bridge of Brives, on the Loire, constructed 1772 by Grangent. It consists of five elliptical arches from 51 to 59 feet in span, and two lesser arches of 10 feet span, placed behind the abutments. Its breadth is 28 feet 6 inches. It is built on a rock, and in great floods the water rises to the cordon without injuring it. This is the first bridge under which the Loire passes, being at this point a rapid torrent.

Bridge of Pesmes, on the Ougnon, constructed 1772 by Bertrand; consists of three segmental arches, 44 feet 9 inches in span. The piers are 6 feet 4 inches thick, and the abutments 12 feet 9 inches. The arches are flattened, and only rise 3 feet 10 inches, or nearly one-twelfth of the chord. The thickness of the vault at the summit is 3 feet 10 inches. The height of the piers, 11 feet 8 inches from the platform.

The bridge of Pesmes is the first in France in which arcs of circles were used whose springings are on a level with high water. The arches sank considerably when the centres were struck, and the want of thickness in the abutments has occasioned some important settlements in one of them, the consequences of which were only prevented by using extraordinary precautions.

Bridge of Pontlieu, on the Huisne, built in 1773 by Voglii. It consists of three elliptical arches, which rise between a third and fourth of the span, which is 57 feet 4 inches. The thickness of the abutments is 14 feet 5 inches. This bridge having no plinth, the parapet forms one, projecting 1 foot 7 inches from the faces of the bridge.

Bridge of Ingersheim, on the Fecht, constructed in 1773 by M. Clinchamp, a military engineer. It consists of three elliptical arches, rising between a fourth and a fifth, with a span of from 50 to 60 feet. The thickness of the abutments is 21 feet 3 inches. It is built on piles 6 feet 6 inches below low water.

Bridge of Drôme, constructed in 1774 by M. Bouchet, on the road from Lyons to Marseilles, with three elliptical arches, rising a third, from 85 to 96 feet span.

This bridge is of very beautiful construction, but the foundations are now too high. The bed of the river has sunk below bridge, and as the foundations are of squared stone, a fall is produced which might occasion the earth to wash away; this has been provided against by driving piles, between which large stones are thrown, to resist the action of the current. The bridge itself is also too high, the floods never rising above half the height of the arches, which is the more evident on comparing its height with that of the banks above the bridge.

Perronet, Jean Rodolphe, a celebrated engineer attached to the Ponts et Chaussées, was born at Surène, near Paris, in 1708. His father was an officer in the French service, and a native of Vevei, in Switzerland, after whose death he devoted himself to the study of architecture, and in 1725 he became a pupil of Debeausire, one of the architects of Paris. When scarcely seventeen years of age, he was entrusted with the superintendence of the great sewer of that portion of the quay, called l'Abreuvoirs, between the bridge of Louis XVI. and the Tuileries; and also of the projecting footway of the Quai Pelletier, near the bridge of Notre Dame. In 1747, the minister Trudaine founded the School of the Ponts et Chaussées, and placed Perronet at its head; he had been for ten years an associate of this body, and had obtained the office of inspector and engineer-in-chief of the department of Alençon. In becoming a director of the new establishment in February, 1747, he received the title of Chief Engineer of the Ponts et Chaussées in France, and in the administration of this celebrated establishment he fully maintained the high idea his talents had inspired, and the great works which were entrusted to him confirmed his reputation. Thirteen bridges were executed from his designs, and eight which were projected show his ability and invention. All are remarkable for some peculiar beauty, and some are masterpieces, never having been surpassed, as Neuilly, Nemours, St. Maxence, and that of Louis XVI. at Paris. Neuilly was the first example of a level bridge, and was commenced in 1768; all the court were present when the centres were struck, in September, 1772, the whole belonging to the five arches were lowered in three minutes and a half. St. Maxence is remarkable for the boldness of its design; that of Nemours, finished in 1805, has undergone some change, but the design was Perronet's.

That of Louis XVI., at Paris, may be considered as peculiarly his own; it unites every species of elegance, convenience, solidity, and easy approach; it was to have been decorated with trophies, but the statues of illustrious men who have done honour to France have been

substituted for them. Perronet was desirous of perforating the piers and abutments, which would have added to its beauty; but he was obliged to abandon the intention, in consequence of the fears entertained by some that such a construction was insecure: he returned to this idea in the bridge of Maxence, and experience has proved that these fears were chimerical. It is a remarkable circumstance, as M. Bertrand has observed, that at the time Perronet was studying architecture at the Louvre, the Academy having proposed a prize for a design for a bridge to be constructed opposite the church of the Madelaine, Perronet was the successful competitor.

His claims to public gratitude are not confined to these works: to him France was indebted for the Canal de Bourgoyne; he also proposed to render the river Yvette navigable, an extremely bold project, which has been superseded by the execution of the Canal de l'Ourque.

During the space of thirty years, in the neighbourhood of Paris alone, more than 600 leagues of road were formed and planted with trees; a vast number were widened, levelled, and rendered convenient for every kind of traffic; and before 1790 nearly 2000 bridges, of various span, were placed under the superintendence of the Ponts et Chaussées.

He was appointed inspector-general of the salt works in 1757, which he held till 1786.

He invented several ingenious machines; among them a saw for cutting off the heads of piles under water; a cart, called after him, which unloaded itself; a drag for cleaning harbours and rivers; a plane table carrying a pencil; a double pump, with a continued action; and an odo-metre, applicable to pumping out. This latter instrument, which may be adapted to all machines, shows the number of turns of the winch made by the workmen employed, and by this means regulates the quantity of work and price; it is also used for measuring the distance travelled on foot or on horseback, which renders it peculiarly useful for military men; and it is so exact as to indicate the retrograde steps.

Perronet was a member of the Royal Societies of London, Stockholm, Berlin, &c., and several other learned bodies. The court of Russia, in 1778, desired him to prepare a design for a bridge over the Neva, which was of a very magnificent character.

Perronet bequeathed his bust, in marble, presented by his pupils, his books, his models, &c., to the Ponts et Chaussées.

His great age, and the respect his services had acquired, preserved him from the revolutionary tempest, and he died universally regretted in 1794.

His published works consist of an account of the bridges of Neuilly, Mantes, Orleans, &c., several memoirs inserted in the Transactions of the Academy of Sciences, a memoir on conducting the waters of the Yvette and Bievre to Paris, and on the means which might be adopted to construct arches of stones from 200 to 500 feet span.

The roads formed by him and various designs were published in three volumes, folio, at the expense of the government.

M. Lesage published, in 1805, an eloquent discourse upon M. Perronet, who may be considered the most distinguished civil engineer in France who had been instructed by the writings of Belidor, in which the first attempts were made to embody what was known of hydraulic architecture: the Italian philosophers at that time had, by their discoveries, awakened in the schools of France an inquiry into the principles of science, and had already pointed out the connection that existed between practice and the mathematical sciences. It was not, however, the high scientific attainments of Perronet that exalted his name, or caused him to be the founder of a new æra in bridge-building, but his nice observance of the prevailing modes of construction, which he set about reducing to a system, and which turned to the best account the movements and employments of workmen and artificers of every denomination; he showed where labour might be saved by the introduction of machines, and instructed them how many difficulties which occur in laying the foundations of buildings in water might be overcome, then unknown or forgotten. We cannot turn over the engravings which represent the labours of this eminent engineer without acknowledging how much we owe him; he evidently belonged to the school of utility, upon which is now engrafted in France the refinements of mathematical analysis: those youths who now aspire to be eminent as civil engineers undergo a scrutinising examination in the physical sciences, and are not admitted to the post of sub-inspector, nor are they introduced to any practical employment, until they have shown a perfect acquirement and thorough knowledge of geometry, mathematics, chemistry, mineralogy, and the sciences connected with them.

The practical man is considered as the *entrepreneur*, or contractor, and never charged with the superintendence of any great work, nor is his opinion valued farther than as regards his capability of performing what he is entrusted to execute: the design in France is left to the learned, and the carrying into effect to the artizan.

Of Perronet's bridges, those at Orleans, Mantes, and Neuilly, exhibit the most profound knowledge of construction, and the principles of the art. The rise of the arches is between a third and quarter of their span; and the manner in which the cofferdams were formed is also deserving of our attention; although to an English engineer there appears to be a lavish employment of material, and too much expended upon the temporary bridges, and tackle to supply the stone &c. for the construction of the piers.

In the bridge at Neuilly there was a novelty introduced in the formation of the soffites of the arches, which were shaped to suit the contracted vein of water, as formed in the entrance and exit of pipes. This was ingeniously executed, by making the general form of the arch elliptical, but the headers followed the segment of a circle: thus, whilst the elliptical arch rose a quarter of the span, the segment of the circle had given to it a ninth rise; by this arrangement it was supposed the flood waters obtained a better passage, and also superior lightness of effect given to the bridge.

Mansard, Gabriel, Hupeau, Gautiers, and Perronet, by means of cofferdams, constructed the piers of bridges on very rapid and deep streams; and in the published works of the latter, the engineer will find all the detail of their operations very beautifully given. Water wheels were usually employed to work bucket wheels, which threw up the water as much as twelve feet, and thus kept the interior of the cofferdams dry.

Bridge of Neuilly, on the Seine. This celebrated work was built from the designs of M. Perronet, and was conducted under his superintendence by M. de Chezy; it was begun in 1768, and finished in 1774, and is placed in the axis of the palace of the Tuilleries, and the centre walk of the Champs Elysées; the line is prolonged by the road along the rising ground of Chante Coq, where it divides, one branch to St. Germain, the other to Bezons.

It consists of five elliptical arches, rising a quarter, 128 feet in span. Their springings are on a level with low water, and there is a distance of 7 feet 5 inches between high water and the neck of the arch. The thickness of the piers is only 13 feet 10 inches. The plan of the starlings is a semicircle; they are slightly curved at half their height. Behind the abutments, the thickness of which is 35 feet 5 inches, are arches for warehouses 15 feet in span. The roads to the warehouses are paved for a great distance, and the slopes are sustained by walls extending 331 feet on each side. The width of the bridge is 48 feet; 31 feet for the road, and 6 feet 6 inches for each foot pavement. The arches are brought to a level with the face of the bridge by cornes de vache, terminated by the prolongation of the arc which forms the summit of the ellipsis.

The foundations are on piles, and were pumped out by cofferdams 7 feet 6 inches below low water; the breadth of the mass on which the piers are built is 22 feet 4 inches; it projects 2 feet 1 inch round the whole of the foundations. The facings are of large squared stone, and the mass of construction is filled in with rubble to 26 feet above low water.

The river formerly divided into two branches at the point where the bridge is built; one part of the island was removed to enlarge the arm on the side of Courbevoie, and the other was filled up; had not this been done, the bridge must have been in two parts. Compared with the other Paris bridges, the water-way is too great, and we must regret that a work so perfect in all its details should have so great a defect in its general arrangement. The inconveniences resulting from this are already perceptible, by an evident silting up in the islands between which it is situated.

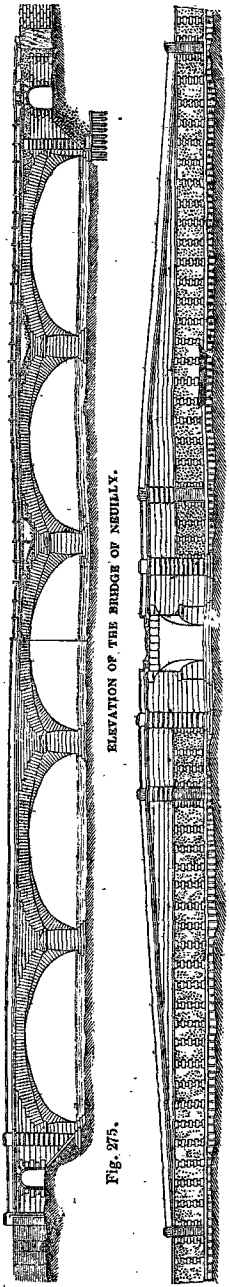


Fig. 275. Fig. 276.

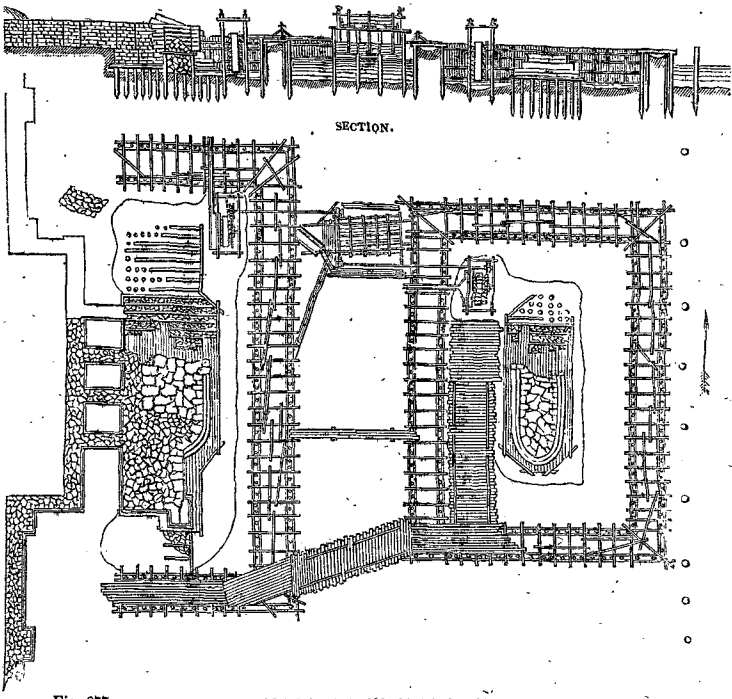


Fig. 277. PLAN OF COFFERDAM AT NEUILLY.

The bridge was terminated for 2,305,000 livres, and the terraces and roads cost 1,172,000 livres more.

Bridge Horbourg, on the Ill, constructed in 1775 by M. Clinchamp, and having five elliptical arches, rising two-fifths, from 55 feet 5 inches to 68 feet 2 inches in span. It is not quite so flat as Ingersheim, but the general arrangement is very similar.

Bridge of Neuville, on the Ain, built in 1775 from Aubry's designs; it consists of two elliptical arches 95 feet 9 inches in span, and is carefully constructed and decorated; the rapidity of the water under the vaults is remarkable. It is built on a rock, which was even excavated to obtain a solid foundation; great difficulty was experienced in constructing the bank which abuts against it; this was carried away several times, and could only be finished by working with great celerity when the water was low. The fall renders the passage extremely dangerous for the floats of timber which come down the river, and which run the risk of being broken on the rocks.

Bridge of Fouchard, on the Thouet, at Saumur, was begun in 1774, under the direction of M. de Voglie, and finished in 1782, under M. de Limay; it consists of three segmental arches 85 feet 3 inches span, and 8 feet 7 inches high. The piers are 12 feet 9 inches thick

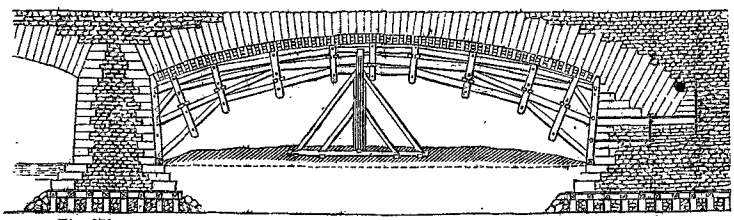


Fig. 278. ARCH OF THE BRIDGE OF FOUCHARD.

below, and 9 feet 10 inches above, and are 4 feet 3 inches below the surface, and the piers are 17 feet high. The abutments are formed by a mass 38 feet 4 inches thick con-

solidated by three buttresses, each 9 feet 2 inches long, and 6 feet 6 inches wide. The section of the voussoirs is continued for a length of 13 feet beyond the opening.

The arches were raised 1 foot 1 inch higher on the working drawings. They remained a year on the centres, at the end of which time the mean sinking of the arch was $3\frac{3}{4}$ inches;

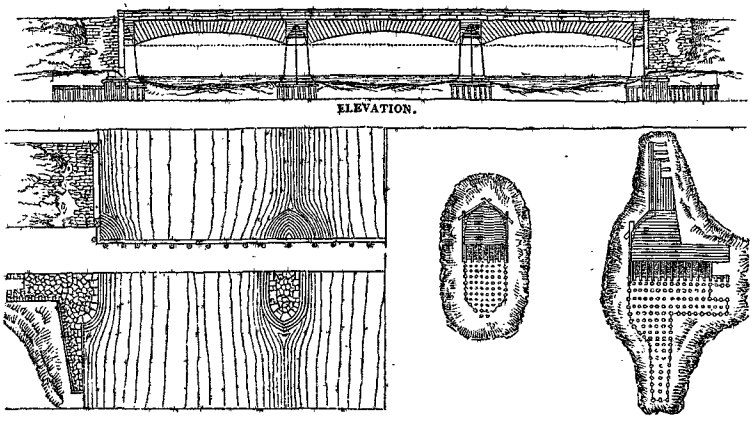


Fig. 279. BRIDGE OF POUCHARD.

forty days after the centres were struck, it was $6\frac{1}{2}$ inches. The parapets and the pavement having been laid very soon after, a new settlement took place, and the parapets over each arch assumed a slight curvature, the versed sine of which was $1\frac{1}{4}$ inches in 1792, and $1\frac{3}{4}$ inches in 1806. These settlements were accompanied with an opening of the joints of the extrados at the springing of the arches, and are less perceptible in the middle than in the two other arches. The vaults were placed on trussed centres, according to Perronet's system.

Bridge of Lavaur, on the Agout, constructed in 1775. It consists of a great elliptical arch approaching a semicircle, with a span of 160 feet 9 inches. The breadth is 38 feet 4 inches, and it has very high return walls. The thickness of the arch is 10 feet 8 inches at the key, and is greatly the cause of the wearing away which has taken place. The accidents cannot be ascribed to a want of strength in the abutments, which are very thick. The sustaining walls, whose convex form tends to diminish the resistance, could not sustain the pressure of the earth, and they have been reconstructed and consolidated on the interior. The water-way appears too great. It is too highly decorated for its situation.

Bridge of Semur, on the Armançon, was built in 1780 by M. Dumorey; it has a single semicircular arch 76 feet 9 inches span. The retaining walls support more than 43 feet of earth, they are 9 feet 7 inches thick, and are strengthened by buttresses. Although there was only a thickness of 13 feet 6 inches of earth between the parapet walls of the bridge, they were not sufficient; large buttresses were constructed to prevent the thrusting out, which seemed evident when the earth was only three-fourths of its present height.

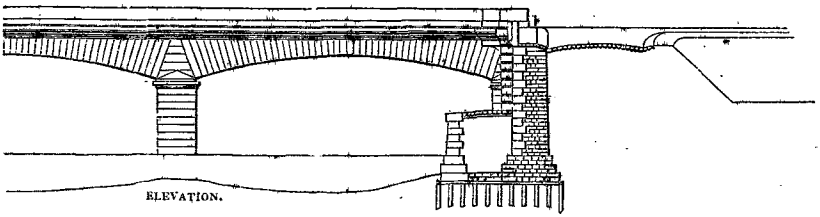
Bridge of Navilly, on the Doubs, built in 1780 by M. Gauthey; it consists of five elliptical arches rising a third, 76 feet 9 inches in span; the piers are 16 feet thick, and are elliptical on the plan; the height of the piers is 8 feet 6 inches, and the platform is 4 feet 3 inches was very below low water.

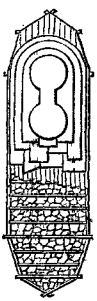
The curvature of the faces of the piers, and the springings of the arches, is prolonged to the starlings, so that the water does not meet any angle or face opposed to the direction of the current, and the contraction it undergoes in passing the bridge is as slight as possible. The arches are constructed with coins of squared stone, the intervals being filled with worked rubble, so as to form natural caissoons.

Bridge of Chalons, on the Saone, is an old bridge of five semicircular arches, from 42 feet 8 inches to 64 feet span, the breadth is 19 feet 2 inches. It was enlarged by Gauthey to 32 feet; above bridge the starlings were triangular, and the enlargement was effected by cornes de vache; below they were rectangular, and archivolts were formed. On the projecting part of the starlings are obelisks for supporting the lamps, they are set half into the wall as high as the parapet. Besides the five great arches, there is a smaller one through which the towing horses pass, and it would be easy, by means of a small iron balcony, to pass the rope under the next arch, which would prevent any interruption in the towing.

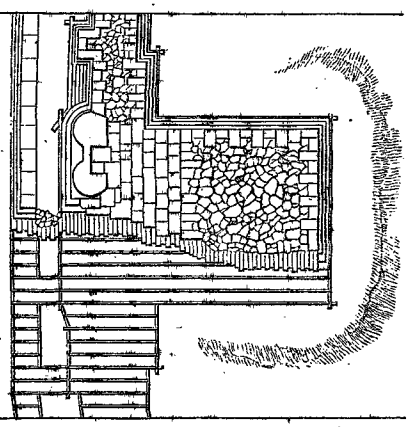
Bridge of St. Maxence, on the Oise, begun in 1774, and finished 1784, after the designs of M. Perronet; the works were conducted by M. Dausse and M. Dumoustier. It is com-

posed of three segmental arches 77 feet, 9 inches in span, and 6 feet 4 inches high. The thickness of the piers is 9 feet 6 inches; the abutments were to have been 24 feet thick, strengthened by three buttresses 19 feet long, but they were carried up in a solid mass





SAINT MAXENCE, PLAN.



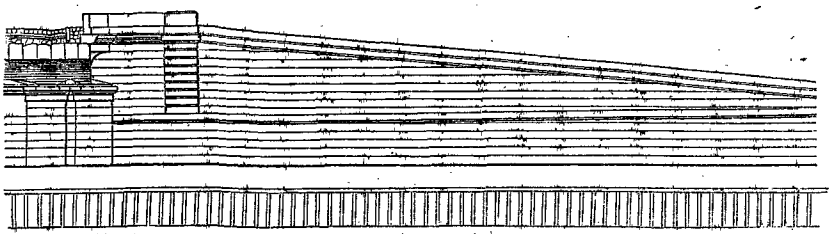


Fig. 280.

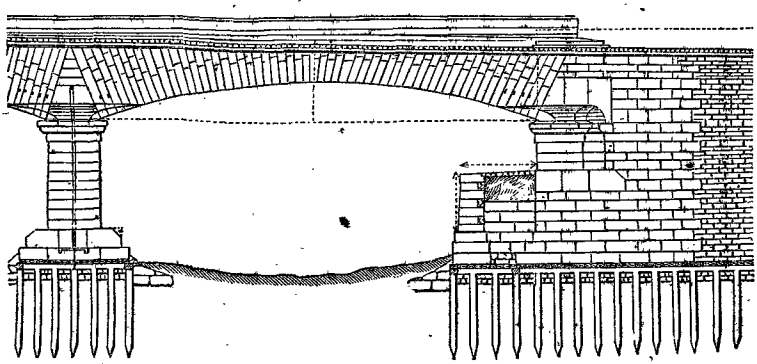


Fig. 281. SAINT MAXENCE, ABUTMENTS.

64 feet thick, which rises to the under side of the pavement. The height of the piers is 19 feet 3 inches, and their foundations are laid in steps which project altogether 6 feet 5 inches. The platform is laid 8 feet 6 inches below low water, which gives a total height of 27 feet 9 inches to the springings, the thickness of the arches is 4 feet 9 inches at the summit. The breadth of the bridge is 41 feet 6 inches; the arches were turned on trussed centres, according to Perronet's system.

The piers are not as usual a solid mass; they, as well as the half piers attached to the abutments, are composed of two groups of columns, leaving a space of 9 feet 7 inches between them. The base of the interval is formed by a reversed arch, and the top is covered by a lunette, which penetrates the vaults of two adjacent arches. The courses of each column are formed by pentagonal newels, which occupies the centre, and five stones cut like wedges applied to each side of the newels; an iron rod passing through the axis of the column traverses the newels from top to bottom; the wedges are united to one another, and to the newels, by cramps; the courses are bolted together, the five first courses of voussoirs, the fourteenth, fifteenth, and twenty-sixth rows are entirely cramped; in the other courses, except the twenty-eighth and the keys, the faces only are cramped. During the construction, advantage was taken of the force of the current to drive the piles, so that there were only three men to each engine, and the stones were raised by cranes.

The arch adjoining the left bank was blown up in 1814, but was not entirely destroyed. On the upper side of the bridge a zone 8 feet 6 inches wide remained, in which the voussoirs, especially at the summit, were fractured and displaced. The middle arch had suffered a slight settlement of 3 inches on the upper, and $6\frac{3}{8}$ inches on the lower side, in consequence of which the joints opened at the intrados of the summit, and the extrados of the springings. The group of columns to the first pier have gone over $\frac{1}{4}$ inch up the stream, and $1\frac{1}{8}$ inch down it. The arch on the right bank was not injured.

After having strutted the pier, the arch was restored by constructing in succession a first zone to the front arch, a second in the middle, and a third to the other front, replacing that which remained after the explosion. Some of the voussoirs were left out to be placed after it had settled; the whole was finished in 1816, and the details, which are extremely interesting, are given in the "Etudes pour l'Art de Construction," by M. Bruyère.

Bridge of Rumilly, on the Cheran, built in 1785 by M. Garella, consists of a semicircular arch 128 feet in diameter; the springing is 10 feet 8 inches below low water. The width is only 23 feet 5 inches. This is the largest semicircular arch constructed in France during the last century.

Bridge of Vizille, on the Romanche, constructed by M. Bouchet, on the road from Grenoble to Briançon. It consists of a single elliptical arch 137 feet 5 inches in span, and 38 feet 4 inches high. The thickness of the keystone is 6 feet 4 inches, and that of the abutments 32 feet.

Bridge of Lempde, on the Alagnon, built 1785, by M. Mauricet, is an elliptical arch 101 feet in span.

Bridge of Homps, on the Aude, constructed 1785 by M. Ducros, consisting of three segmental arches, one-sixth of a circle, with a span of 70 feet 2 inches; the arch on the faces is flatter than that of the centre of the vault, and small cornes de vaches are constructed, which terminate on the crowns of the starling.

Bridge of Chateau-Thierry, on the Marne, begun 1765, finished 1786, after a design by M. Perronet: it consists of three elliptical arches rising a third, 51 feet 2 inches and 47 feet 3 inches in span; the breadth is 35 feet 2 inches; the thickness of the piers is 14 feet 4 inches, and that of the abutments, which are strengthened by return walls, is 15 feet. The foundation is laid on a frame of carpentry, supported on piles 13 feet 7 inches below the springing of the arches; the thickness of the keystone is 4 feet in the centre arch, and 3 feet 9 inches in the two others.

Bridge of Mazères, on the Lers, built in 1787, by M. Pertinchamp; it is composed of an ancient segmental arch, 70 feet 2 inches in span, and two modern semicircular arches, 44 feet 7 inches and 48 feet 6 inches in span. They are decorated with an archivolt, and the pier, which has no starlings, is faced by pilasters. The decorations have a tolerably good effect, but the omission of starlings is in most cases attended with inconveniences.

Bridge of Chavannes, at Chalons-on-the-Saône, constructed in 1787, at the extremity of one of the faubourgs, by M. Gauthey. It consists of seven elliptical arches, rising a third, 42 feet 8 inches in span; the height of the piers is 8 feet 6 inches, and the thickness 15 feet, the width is 32 feet.

The situation not permitting the pavement to be sufficiently elevated, high floods rise to the key of the arches, and in order to compensate for the diminution of water-way the river undergoes in rising, oval openings 8 feet 6 inches wide are made in the upper part of the piers. The foundation is a coarse gravel, so compact that the piles could not be driven more than 4 feet 3 inches into it. Constructions raised on such soils being very liable to settlements, a timber platform was placed under the bridge, 52 feet 6 inches wide, and 3 feet 3 inches thick, the upper surface being 3 feet 3 inches below low water.

Bridge of Rosoi, on the Hyeres, erected in 1787, from a design by M. Perronet, and consisting of two segmental arches, equal to one-sixth of a circle, 25 feet 6 inches in span; the thickness of the abutments is 12 feet 9 inches, and that of the pier 6 feet 4 inches; the thickness of the keystone is 3 feet. The arches and facings are of very hard sandstone carefully dressed; the breadth is 35 feet 2 inches.

Bridge of Brunoi, on the Hyères, constructed in 1789, and, like the preceding, from M. Perronet's designs; it consists of three arcs equal to one-sixth of a circle, and 19 feet 2 inches in span. The thickness of the piers is 3 feet 9 inches, and that of the abutments 10 feet

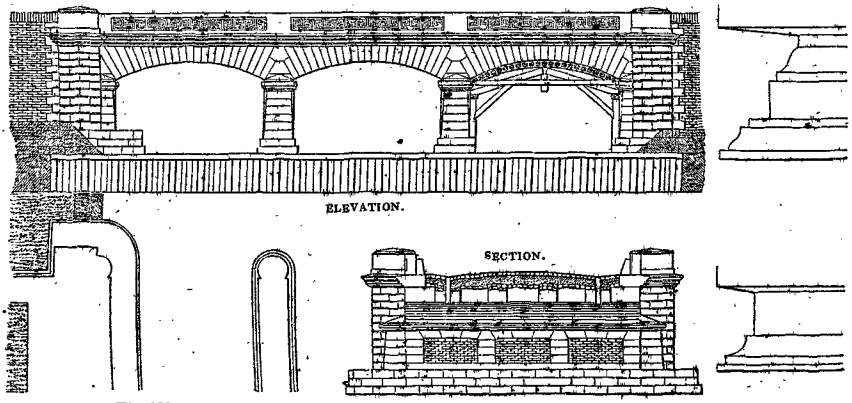


Fig. 282. BRIDGE OF BRUNOI.

8 inches; the springings of the arches are 7 feet 5 inches above the last set-off; the thickness of the keystone is 2½ feet. The bridge is entirely constructed of squared stones, and the foundations are laid on a platform 3 feet 3 inches thick; the total width is 30 feet 4 inches.

Bridge of Louis XVI. at Paris, begun 1787, and finished 1791, from M. Perronet's design. It has five segmental arches of 75 feet 9 inches, 85 feet 3 inches, and 94 feet span: the perpendiculars are 6 feet 4 inches, 8 feet 9 inches, and 9 feet 9 inches. The thickness of the piers is 9 feet 6 inches. The starlings are formed by columns 9 feet 6 inches in diameter, rising to the cornice; three-fourths of their radius are, however, hidden within the piers. The abutments are 51 feet 3 inches thick. The width of the bridge is also 51 feet 3 inches, and each footway is 8 feet wide. The thicknesses of the keystones are 3 feet 2 inches, 3 feet 3 inches, and 3 feet 8 inches, not comprising 10 inches for the prolongation of the lower part of the architrave.

The springings of the arches are 19 feet 2 inches above low water. The piers and abutments are built on steps with a projection of 6 feet 4 inches. The platform is 5 feet 6 inches below low water. The stone was from the works at Gare and the ruins of the Bastille.

This bridge was constructed and decorated with the greatest care. The elevation is crowned by an entablature supported on modillons; the parapet is formed of balusters. Above the starlings of each pier are square socles intended for the support of iron obelisks, but for which colossal marble statues have now been substituted. It is to be regretted that their proportions, as well as those of the pedestals, are too large. In the bridge of St. Angelo at Rome this point is much better attended to.

Bridge of Gignac, on the Herault, begun 1777, finished 1793, by M. Garipuy: it consists, of two semicircular arches 83 feet in span, with cornes de vache, and a great elliptical arch rising a third, 160 feet 9 inches in span, on piers 8 feet 6 inches high, ornamented with an archivolt: their thickness is 25 feet 7 inches.

Bridge at the union of the Southern Canal with that of Narbonne. The bridge is built at the point where the southern canal makes an elbow, so that it is the means of uniting three branches of canals and three of roads.

The arches are arcs of circles, in order to accommodate the towing-paths of the canals. The faces of the bridge are curved to facilitate the junction of the roads.

M. Belidor has described a similar bridge situated at the junction of the Ardres and Calais canals, which unites four arms of canals and four of roads. The arches are semicircular.

Bridge of Herault, on the road to Nice. This arch, designed by M. Grangent is 105 feet in span, and 19 feet high; both extremities are on the rock.

Bridge of Nemours, on the Loing, constructed by M. Boistard from designs by M. Perronet. It was completed in 1805, and has three segmental arches 53 feet 3 inches in span, and 3 feet 9 inches high. The thickness of the piers is 7 feet 2 inches, their height 13 feet 10 inches above the water, and 19 feet 2 inches above the platform. The footings project 3 feet 2 inches all round. The thickness of the abutments is 16 feet 10 inches, and they are consolidated by three buttresses 17 feet long, and 6 feet 4 inches thick. The thickness of the keystone is 3 feet 2 inches. The width of the bridge is 41 feet 6 inches.

This work was constructed with the greatest care, and notwithstanding a considerable flattening of the arches, no settlement manifested itself. M. Boistard has published some experiments which he made during its progress, and on the effect of the machines used in pumping out the water.

Bridge on the Road of the Simplon consists of two bays 42 feet 8 inches in the opening. They are built partly on a rock and partly on a pier from 20 feet to 23 feet thick and 95 feet high. This arrangement was adopted in order to afford an opportunity of breaking it down in case of war; otherwise the rocks might have been united by a single arch 98 feet 5 inches in span.

Bridge over the Ravines of the Côte de Maires. This as well as other bridges of the same kind was built on the road from Viviers to Puy. The two arches, placed one above the other, are from 33 feet to 40 feet high. Although constructed of granite and basalt, they are considerably decayed; for after floods the ravines which they traverse bring down masses of rock from 10 feet to 12 feet square, which break the stone, and in some cases carry it away. In such localities it would be infinitely preferable to raise a thick wall to block up the valley, which is soon filled up with debris. The water then falls in cascades to the bottom of the wall, which, being founded on the rock, cannot be injured.

Bridge of Roanne, on the Loire, was begun in 1789. It consists of seven elliptical arches rising a third, 76 feet 9 inches in span. The thickness of the piers is 15 feet, and the bridge is further strengthened by a general ground-work 3 feet 3 inches thick, and 3 feet 3 inches below low water, composed of a bed of beton, 2 feet 1 inch thick, which was suffered to harden for a year previous to covering it with masonry. Above and below it rows of piles were driven, and, in addition, on the lower side a jetty of rubble was constructed, 8 feet 6 inches deep, maintained in the same manner. The width of the bridge is 38 feet 4 inches, 25 feet 7 inches for the road, and 5 feet 10 inches for each footpath.

There were formerly two wooden bridges, separated by an island, which have been successively carried away: one arm being in a great measure filled up, and not allowing a sufficient water-way, the bridge which crossed it was destroyed by a flood. The other shared the same fate a few years after, from the effects of a bar formed by poplars, which the river brought down in great numbers.

Bridge of Bellecour, on the Saône at Lyons, begun at nearly the same time as the preceding. It has 5 elliptical arches, 68 feet 2 inches in span. It is situated in a very contracted part of the river, where the depth was from 16 to 20 feet below low water. It was built by caissoons, and the piles are cut off 9 feet 10 inches below the surface.

Bridge of Montlion, on the Durance, commenced in 1805 by M. Delbergue-Cormont; it is a single elliptical arch, rising one-fourth, and 101 feet 8 inches in span. On one side the foundations are on the native rock, and on the other on piles.

Bridge of St. Diez, on the Meurthe, constructed from designs by M. Lecreulx, and consisting of three segmental arches, 39 feet 4 inches in span, and two small semicircular arches 13 feet span. The height of the first is 3 feet 3 inches. It is raised on piers 5 feet 3 inches both in height and thickness.

Bridge of Montélimart, on the Roubion, is on the road from Lyons to Marseilles, and consists of three elliptical arches 63 feet 11 inches in span. Its width is 28 feet 9 inches.

Bridge of Maligny, on the Serin, built by M. Werbruge. It consists of a nearly semicircular arch, 84 feet 3 inches in span. The foundation is 4 feet below low water; it is entirely rubble, from 3 to 4 inches thick, and from 10 to 11 inches long, chisel-dressed, and squared like regular masonry; the waste was great, the stone being reduced to one-half its original bulk. To prevent the centres from starting at their summits during the construction of the arch, and to avoid loading them, the arches were begun in different places, and were locked together by three keys; they remained fifteen days on the centres. The bridge was solidly built, but the form has become slightly altered, the two heads having started from their original position, and assumed a curvature of 7 inches perpendicular.

Bridge of Rieucros, on the Douctoire, begun 1770, finished 1790, by M. Garipuy. It consists of three elliptical arches, 55 feet 5 inches in span; the piers have no starlings.

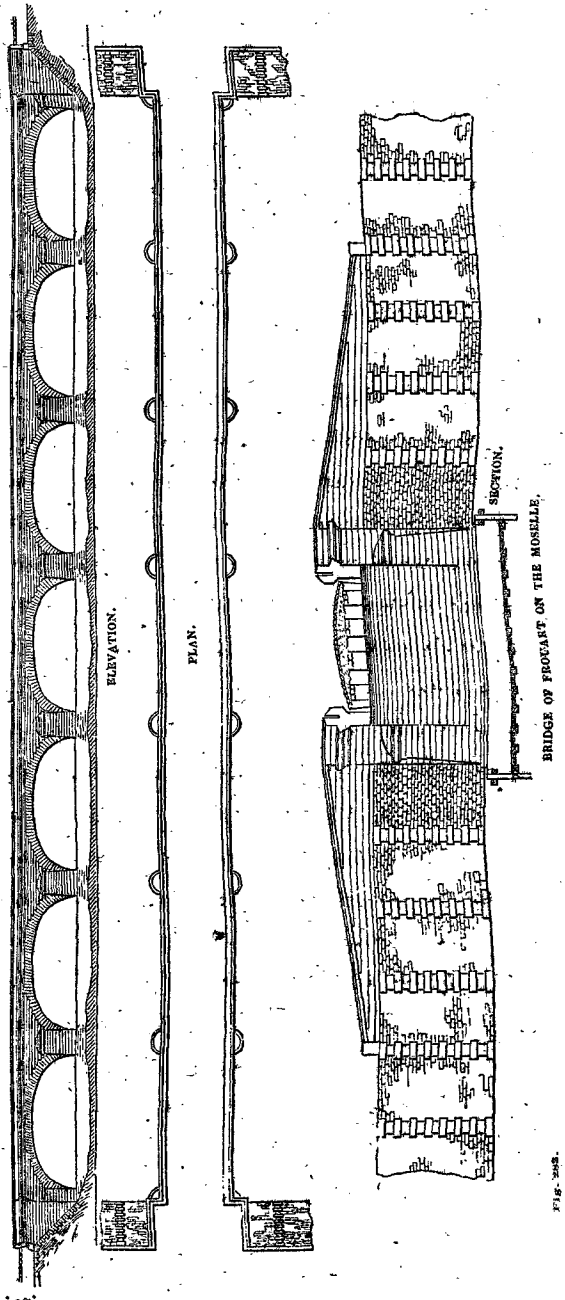
Bridge of Mireppis, on the Lers, also the work of M. Garipuy, was begun 1776, and completed 1790. It has seven arches, one-sixth of a circle, 64 feet span. The plan of the starlings is a mixtilineal triangle: the width is 25 feet 6 inches; the foundations are 19 feet 8 inches deep, on a solid soil.

Bridge of Frouart, on the Moselle. This fine bridge was constructed in 1788, by M. Lecreulx, to replace an old one which had been founded at the level of low water, and

was carried away by a flood in 1788. It consists of seven elliptical arches, with a span of 64 feet, and rising between a third and a fourth; the thickness of the piers is 13 feet 10 inches; the plan of the starlings is semicircular, and they have a flattened spherical top.

The abutments are formed of a mass 35 feet 2 inches thick, and 47 feet wide; the width of the bridge is 32 feet. The foundations were laid by means of cofferdams, on a platform 6 feet 6 inches below low water, and were surrounded by a row of piles; the soil is a solid gravel; the arches were constructed on trussed centres. It cost about 440,000 francs.

In placing the voussoirs around the elliptical arches, a greater depth was given to those of the upper part, which formed the flattest portion of the arch, or rather those which had the longest radius. We find that most of the bridges erected at this time in France had the depths of the voussoirs proportioned to their several radii: the very reverse of this system was adopted by Mr. Rennie in those he built over the Thames; that able engineer gave the greatest length to those voussoirs which commenced the arch, and gradually diminished it towards the key. We shall find, by a comparison with one of the arches of London Bridge, that in our present example this difference is very evident; but those we shall describe afterwards in France are constructed in a different manner, and several writers upon bridges point out the necessity of doing what was, perhaps, first practised in England, viz. that of placing the first voussoir upon an inclined, in preference to a horizontal bed, as was commonly done: by such an arrangement, there was less probability of the whole sliding off the pier, or along the abutment, and the pressure of the arch was delivered below the springing.



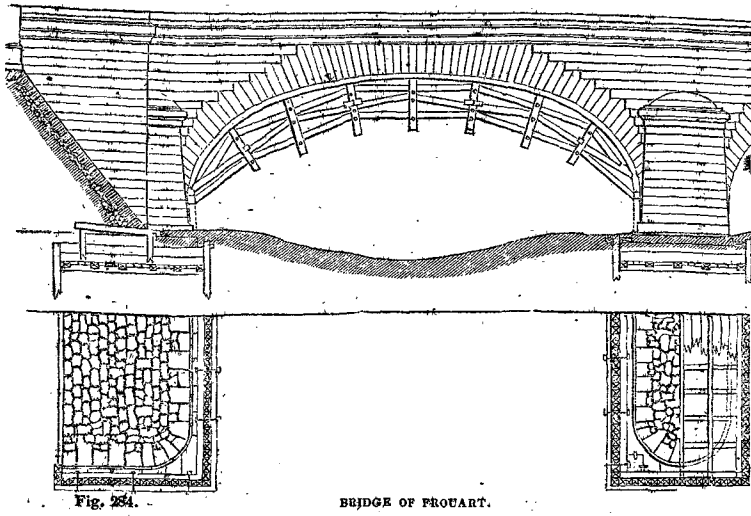


Fig. 284. BRIDGE OF ROUART.

Bridge of Rouen, on the Seine: the remains of a stone bridge built by Matilda, wife of Henry II., Duke of Normandy and King of England, about 1160, are still visible at Rouen. It was 480 feet long, and composed of thirteen arches; several of these having fallen, and others carried away, the thoroughfare was closed in 1564, and in 1626 it was replaced by a bridge of boats.

The new bridge was decided upon in 1810. The designs were made by M. Lemasson, and the work begun in 1811. In 1812, it was placed under the direction of M. Lamandé, who proposed several changes, the chief of which related to the manner of founding the piers.

It consists of two equal parts, which may be considered as two distinct bridges, separated by a circular mass which forms the lower extremity of the island of La Croix. They are not in a line with each other, their axes comprising an angle of 146°, which arrangement was adopted in order that the two bridges might be perpendicular to the current of the two arms of the river, and directed to the points of commencement of the two new roads.

Each bridge consists of three segmental arches. The span of the middle one is 101 feet 8 inches, and the versed sine of the arc of the intrados 13 feet 9 inches. The span of the lateral arches is 85 feet 3 inches, and their versed sine 10 feet 7 inches. The spandrils are decorated by a semicircular niche, placed over each pier. The springings are 16 feet 9 inches above low water. The thickness of the arches 3 feet 5 inches. The piers, terminated by semicircular starlings, are 10 feet 5 inches thick at the springings, and 11 feet 10 inches at the base. The width of the lowest course of footings is 16 feet 8 inches; the piles which support it are cut off 9 feet 9 inches below low water. The abutments are formed by a mass 59 feet thick and 60 feet 9 inches wide, in the middle of which an arch is constructed, 13 feet span, and 12 feet 4 inches high to the key-stone. This mass was founded on piles 3 feet 6 inches below the surface. The cornice on each side has a fall of 1 in 34 from the middle of each bridge, which slope extends to the approaches. The total width is 49 feet 2 inches, of which 29 feet 6 inches is for the roadway and 7 feet 10 inches for each foot pavement. The embankment required was nearly 16 feet in depth, and extended to the houses.

The abutments were founded by cofferdams, on piles 39 feet 4 inches long, 4 feet 3 inches apart: they are defended by a row of piles touching each other. The depth at low water is 28 feet 6 inches, and the side rises about 6 feet 6 inches. The piers were founded by caissoons on piles 49 feet 2 inches long, and 3 feet 3 inches apart.

The foundation is surrounded by a row of piles touching each other, retained by bands; it is farther strengthened by a similar row 5 feet 2 inches wide, forming a starling round the piers, the heads of which are 19 feet 8 inches below low water. The interior both of the piers and the starling was dredged, and filled with concrete, and the exterior defended by rubble work.

The arches were placed on fixed centres formed by three pairs of principals, supported by two rows of piles.

Bridge of Sevres, over the Seine, on the road from Paris to Versailles, was designed by

M. Becquey de Beaupré, and executed by M. Vigoureux; it was finished in 1820, and consists of nine principal semicircular arches, 59 feet in span, and two lesser 16 feet 4 inches in span for the towing path. The thickness of the piers is 11 feet 5 inches; the width of the bridge 42 feet 7 inches. It occupies the situation of an old wooden bridge, and the axis is in the direction of the dome of the Invalides. The piers were founded by means of caissoons. The arches were constructed on trussed centres, which did not change their form during the placing of the voussoirs.

All the arches were keyed in July, 1815, except the first on the right bank, where there still remained fourteen courses of voussoirs to place, when orders were given to break down the bridge, and the centre of this arch was first set on fire, and the fourth blown up by two discharges, which caused the rupture of some of the inner voussoirs of the arches, and it was afterwards discovered that settlements had taken place in the third, fourth, fifth, and sixth piers, the greatest of which was 2⅜ inches. In 1818, the sixth pier was loaded with 112 tons, without any movement resulting; it was thought fit, however, to discharge the weight by means of arches in the piers. The foundation piles were 3 feet 11 inches apart, and each carried a weight of fifty-two tons; the voidings, however, diminished this weight by about five tons and a half. A general foundation was also constructed by throwing in rubble. The settlements are attributed to the effect of the explosions; but they would not, perhaps, have taken place had the piles been less loaded, or the intervals between them been filled in with hydraulic masonry to a height of 6 or 8 feet between the ground and the tops of the piles, instead of with masonry laid in common mortar, which does not harden under water.

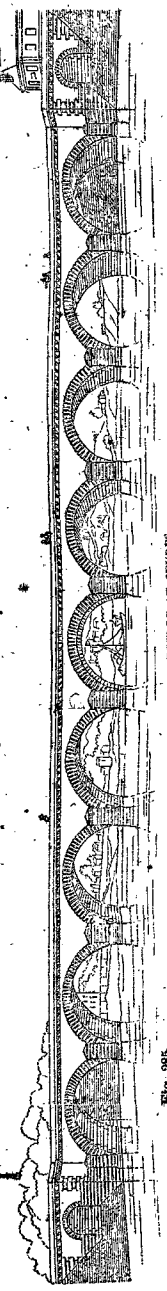
In this beautiful example, the roadway is kept perfectly level throughout, and the arches are all of the same span; this was rendered necessary, as the banks on each side of the river were low, and it was not deemed advisable to raise the crown of the roadway, which might have been done on the Paris side, but towards the town of Sevres, it would have been more difficult to accomplish, as the houses on each side of the street, and the entrance to the royal park, would have been equally inconvenienced. The piers, all of the same dimensions, are of great strength, their width being nearly equal to a fifth of the span of the arch.

The faces of the voussoirs, which are rusticated and rounded, increase in depth towards the springing; the effect is improved by this arrangement, and we have an additional strength given where it is most required.

For the piers, abutments, and arch stones, the best stone which could be obtained was made use of, and apparently the atmosphere has produced little change upon it: as the stones laid in the quarry, so are they bedded, and their dimensions and proportions are well defined for their respective situations. In the spandrills and wing-walls, there does not appear to have been sufficient attention paid to the backing, and inferior material is said to have been used.

This bridge, which has a decidedly Roman character, is one of the best where semicircular arches have been preferred to the elliptical; the same centre would serve for all the arches, and there is some economy in such an arrangement; but the piers occupy together upwards of 90 feet, while the breadth between the abutments or water-way does not exceed 622 feet: by the adoption of a flatter arch, fewer piers would have been required, and consequently more water-way would have been obtained: but the whole is deservedly much admired, and its design seems in harmony with the scenery around, and with the character of the river: over a stream where the tide rose considerably, or the navigation was more important, a bolder design might have been introduced.

The elevation and section through the piers show its solid construction, and the form also of its starlings: over the arch are well contrived drains, which lead off the waters that fall upon the roadway, and conduct them behind the spandrills into the stream below: the blocking course, which forms the parapet, is supported upon a bold block cornice, and the absence of all balustrade and railing



BRIDGE AT SEVRES.

Fig. 285.

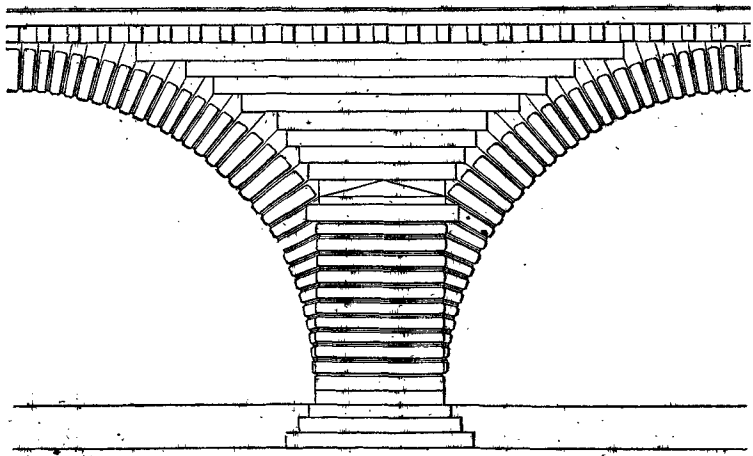


Fig. 286. PIER OF BRIDGE AT SEVRES.

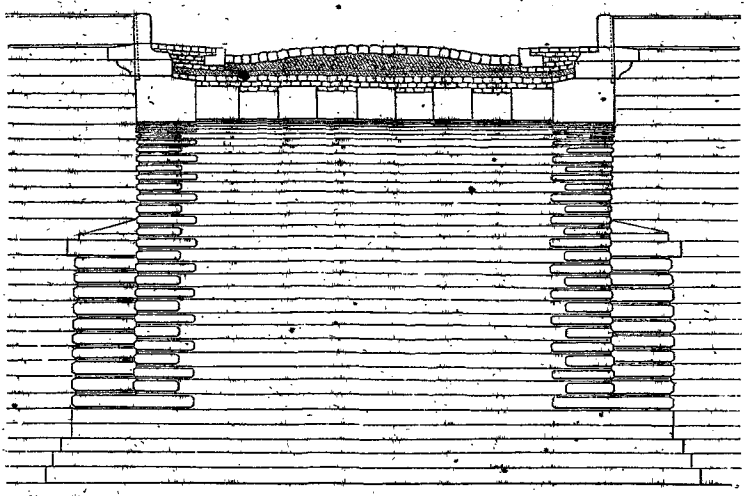


Fig. 287. SECTION OF BRIDGE AT SEVRES.

greatly adds to the effect of the structure. The roadway is paved throughout, and at the sides beyond the water channel is a footway, laid with a gentle inclination.

Bridge on the Serrière, near Neufchatel, constructed by M. Ceart; the foundations are on a rock, and it consists of a semicircular arch 69 feet 3 inches in span. The thickness of the arch is 5 feet 2 inches; that of the abutment, which does not rest against the rock, and which forms a pier 14 feet 1 inch high, is 16 feet 5 inches. This bridge, 26 feet 3 inches wide from one head to the other, is a good example of bridges of one arch constructed over small rivers in the departments of France: the engineers cotemporary with Ceart, and particularly those who, like him, had studied the Roman remains in Provence, seem to have universally adopted the semicircular form for their arches, and to have constructed their abutments with great solidity: the refinements which have been introduced in modern times have greatly economised material, the thickness of the voussoirs at the crown has also been reduced. Boistard and Berard have pointed out how erroneous it is to consider the strength of an arch as dependent upon the weight of its key-stone: the great depth in the present example is an unnecessary load, and by its adoption every other portion, down to its abutments, has been proportionably increased, without the whole acquiring any additional strength.

Bridge of the Military School, formerly bridge of Jena, on the Seine at Paris, is situated in the prolongation of the axis of the Military School and of the Champ de Mars. The erection of a bridge in this situation was decided on in 1806, the arches of which were to have been of cast-iron; but in 1808, Lamandé obtained permission to execute it on the present design, which is composed of five equal segmental arches, 91 feet 10 inches span, and 10 feet 9 inches high. The thickness of the arches is 4 feet 8 inches; their springings are 20 feet 1 inch above the surface. The piers are 9 feet 10 inches thick, and have semicircular starlings; they were founded by caissoons on piles cut off 5 feet 4 inches below the surface, and 3 feet 9 inches apart. The abutments are formed of a mass 49 feet 2 inches thick, and 59 feet wide, 13 feet 1 inch high at the level of the springing, of rough stone, bonded horizontally and vertically. The width of the bridge is 46 feet, that of the road-way 30 feet 7 inches, and of each footway 7 feet 10 inches; it is crowned by a level cornice supported on consoles. There are at the entrance four pedestals for equestrian statues.

The arches were constructed on centres formed by three courses of principal timbers, disposed according to the system of M. Perronet, but strengthened by two rows of piles. The motion of the arch during the placing of the voussoirs was scarcely perceptible. The centres were easily struck by first removing the struts applied against the piers, and then the intermediary piles. The total sinking of the arch was at most 6 inches.

The semicircular arch having its springing upon the horizontal line, or diameter, its load or weight acts perpendicular, or in the direction of its gravitation, and it has not that tendency to spread and exert a lateral thrust, and consequently does not require such solid abutments, as that which is the portion of a circle or a segment; but the semicircle cannot be always introduced, as its height would require that all the approaches should be elevated, and where the banks of a river, as in the present instance, are low, it is not very practicable.

The segmental arch obviates this objection, and also can be executed with less material, but the lateral pressure being augmented, more consideration is required for the strength of the abutments; in an arch of this description, the thrust increases as the angular measure of the length of the arc diminishes. The arches of the bridge of Jena are very nearly those produced by the side of a hexagon, and its portion of the circle: they seem to have been set out by striking a curve round one side of an equilateral triangle, which is as flat a segment as has hitherto been introduced. The horizontal thrust of such an arch requires a provision not only that it may bear its own weight, but also any which may be added to it; the piers may be made light, where the arches comprise only sixty degrees, as the weight is carried to the extremities. In the five arches of this example the abutments received the greatest attention; their thrust, it was considered, acted upon the two extremities of the bridge, where the masonry was sufficiently strong to resist it. The flatter the arch or the greater the segment, the less width is required to be given to the piers, but the masonry saved in the piers must be given at the abutments.

During the occupation of Paris by the foreign powers in 1814, the Prussian army were desirous of destroying a monument consecrated to one of Napoleon's most brilliant victories, and preparations were made for undermining the lower part of the piers; but this act of barbarism was countermanded, and the evidences of it have since been effaced.

The bridge of the Ecole Militaire combines both simplicity and elegance, and may be considered to possess the highest degree of beauty that can be imparted to constructions of this description.

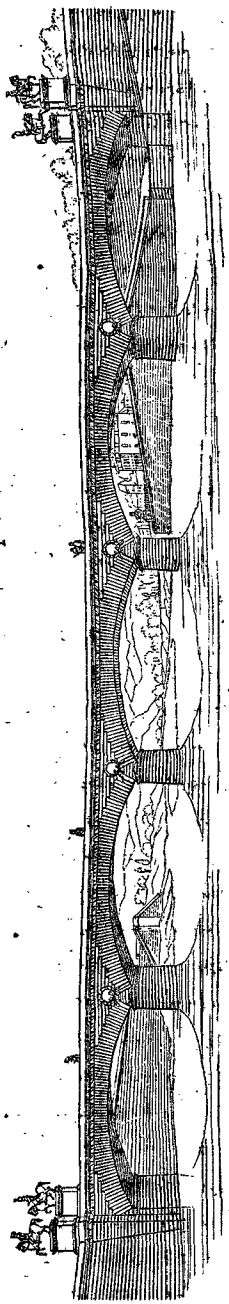


Fig. 288.

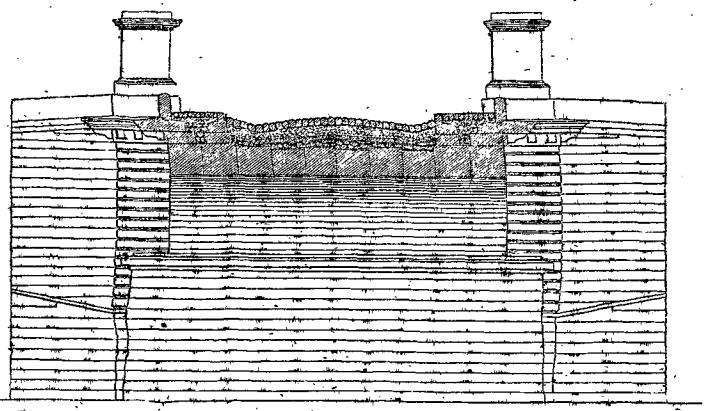


Fig. 289. SECTION OF BRIDGE OF JENA.

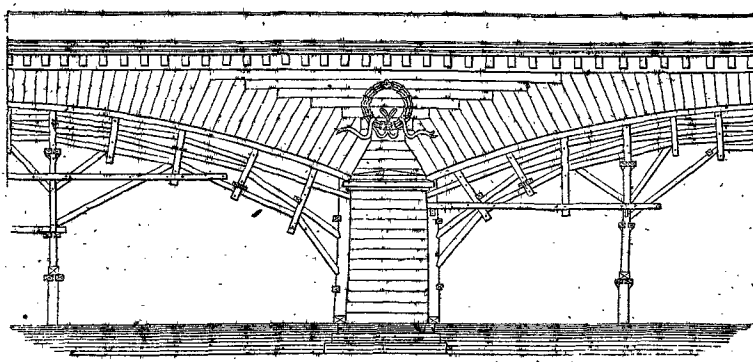


Fig. 290. BRIDGE OF JENA.

Bridge of Bordeaux, on the Garonne, consists of seventeen stone arches resting on sixteen piers and two abutments. The length between the abutments is 1590 feet, and the width 48 feet 6 inches. The arches are segments of circles, whose versed sine is one-third of the chord. The seven middle arches, which are equal, are 86 feet 11 inches span; and the five first on each side are successively 68 feet 10 inches, 72 feet 6 inches, 76 feet 1 inch, 79 feet 8 inches, and 83 feet 3 inches. The thickness of the piers at the springing of the arches is 13 feet 9 inches.

The Garonne has a general depth of 22 feet, and in some places of 33 feet at low water. The tide rises twice a day to 13, 16, and even 20 feet above this level. The currents in both directions have occasionally a velocity of more than 10 feet in a second. The river flows over a bed of sand and mud easily displaced. The borings gave a resisting soil at 39, 49, and 52 feet below low water. Two hundred and fifty fir piles were driven under each pier, and cut off 12 feet 3 inches below low water with a circular saw.

Before the piles were driven, a large frame was sunk 1 foot 6 inches below the plane of cutting off, to regulate their position and their distances apart, formed of strong pieces of timber placed longitudinally and transversely; the stones which fill the spaces between the piles, from 3 feet 3 inches to 8 feet 2 inches above the bottom, kept the heads of the piles steady, and are levelled even with the foundation. All the bases of the piers, and the water-way under the arches, are covered with a pavement of rubble work, the stones which compose it being enveloped by the mud which is deposited in their interstices, presents, as the experience of fifteen years proves, a mass impervious to the erosive action of water.

The masonry of the piers was raised in a caissoon of a pyramidal form at the base, and the upper part of the sides rising vertically to a height of 25 feet 10 inches above the plane of the heads of the piles with a length of 78 feet 8 inches, and a breadth of 27 feet 2 inches at the level of the same plane.

The centres for the arches were composed of fifteen pair of principals, each of which formed as it were a single voussoir; the pieces were put together on two boats united and raised in a body by means of crabs placed on the scaffold of the piers. By this simple and economical process the whole centre of an arch 86 feet 11 inches in span was placed in three days.

Before the arches were commenced the piers were proved by loading each with a weight of 3924 tons, in the form of a pyramid composed of stone blocks and rubble; the weight of the arches was also diminished by lightening the internal mass of the tympanum and every portion that was not necessary for the stability of the extrados, by constructing galleries the lengthways of the bridge; these again were traversed breadthways by vaults of the same form and span. These precautions effected a diminution of 3280 cubic feet in the weight borne by the piers; greater facilities were thus afforded for examining the interior of the bridge, ascertaining if any filtrations or settlements had taken place, and making any requisite repairs.

Squared stone and brick were both employed in the masonry; the archivolts are entirely of freestone, and they are united by rows of voussoirs in horizontal lines, so as to form caissoons filled with brick; the heads are relieved by openings, in order to facilitate the passage of the various substances carried down by the rapid currents of floods, which, without great precaution, might seriously injure the arches. The Garonne rises occasionally to very great heights; in 1770, the increase was more than 23 feet above low water; this required an extraordinary elevation to be given to the bridge, which, added to the necessity of uniting two banks sometimes 3 feet under water, have prevented the causeway from being made entirely on the level, which is only maintained over the seven middle arches and half of the two next; the remaining portion has a fall of about one in eighty.

Quay walls, 574 feet long, are retained on each side of the abutments, at the extremities of which steps descend to the river. The river forming too great an elbow just at the bridge a dyke has been raised on the right bank above bridge, of rubble work, 16,404 feet long; in some places 46 feet high, and more than 98 feet base. Its effects were such that in a few months the bar called "la Manufacture" was entirely removed. The bed of the Garonne was deepened on the left bank, and the property on the right bank increased by a clayey deposit of 100 hectares in surface, of which several portions are now covered with vegetation and plantations, and some are under cultivation.

Since 1820, a diving-bell has been used for any repairs that might be required in the rubble work, and its general stability has thus been satisfactorily ascertained.

Bridge of Libourne, on the Dordogne, consists of nine semicircular arches, each of 65 feet 7 inches span, resting on eight piers 12 feet 6 inches thick at the springing. All that has been said of the bridge of Bordeaux, both as to form and system of construction, applies to that of Libourne. The piling, the frame, the rubble work, the caissoons, the centres, the voussoirs, the mixture of brick and stone, the voiding of the upper mass of the piers, the double slope from the middle, and the architectural decoration, were projected and executed on the same principles. The roadway on this bridge like that at Bordeaux is formed by a brick arch carrying masonry laid in hydraulic mortar, covered with a dressing of broken stones.

The footways at Bordeaux are paved with small pebbles of different colours laid in concrete, forming lozenged-shape compartments. Those of Libourne are paved with brick laid flat in mortar. Each entrance of both bridges has two lodges, one for receiving toll, the other for the police. Their architecture is simple; those at Bordeaux are ornamented with a porch formed by two pilasters and two columns.

The foundation piles at Bordeaux and Libourne were shod, for the first time, with conical cast-iron shoes, with a wrought axis in the centre; this method has since been employed in several great hydraulic operations in France, on account of the resistance it affords, and its great economy.

The two bridges were built from the designs and under the direction of M. C. Deschamps, inspector-general of the Ponts et Chaussées.

The Pont du Louvre, or *des Arts*, was the first iron bridge constructed in France under the auspices of M. de Cessart, inspector-general of the Ponts et Chaussées, and its execution was confided to M. Didon. It is composed of nine arches, each measuring between the piers 56 feet 8 inches, the piers being 6 feet 6 inches in width.

The arches are composed of five ribs, placed about 6 feet 8 inches apart; the ribs are cast-iron, 6 inches deep, and about 3 inches wide, formed in two thicknesses. The chord of the arch is 60 feet 8 inches, and its versed sine 12 feet.

When iron was first applied to bridges in France, its properties were by no means understood by the engineers; they, in general, attributed to it a greater strength than it possessed, and consequently the first constructions in this material were very faulty and defective: what had been executed in England they greatly admired, and were anxious to imitate, but the cost of iron being much higher in France, they adopted too strict an

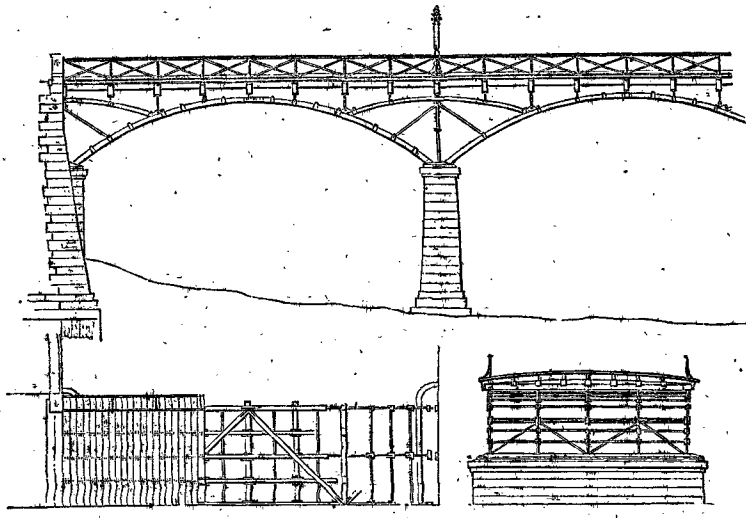
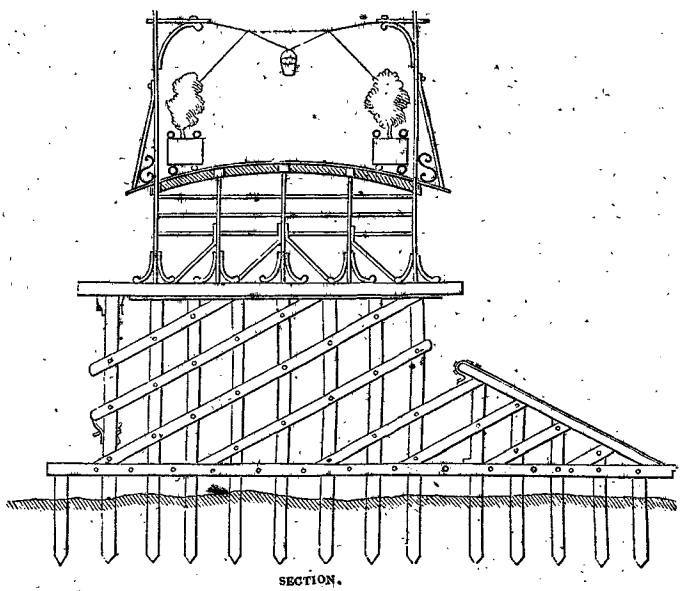


Fig. 291. BRIDGE OF THE LOUVRE.



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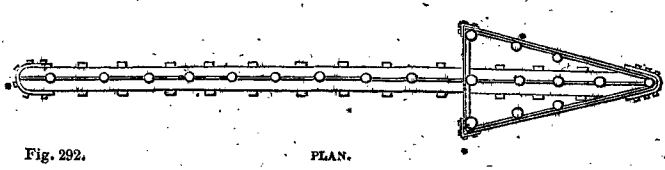


Fig. 292. PLAN.

economy in its application, and some of their first iron bridges over the Seine gave way, or were afterwards remodelled or removed.

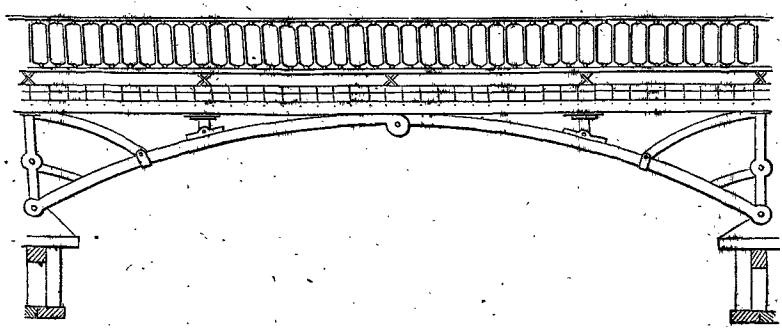


Fig. 293. BRIDGE OF THE LOUVRE.

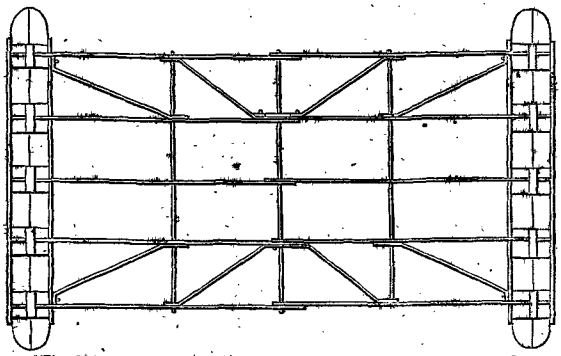


Fig. 294. BRIDGE OF THE LOUVRE.

Poyet, an architect of considerable eminence, who gave the design for the beautiful façade of the Chamber of Deputies, turned his attention to constructions of iron, and laboured much for its general introduction.

This foot-bridge has been greatly admired for its lightness; but, as constructed in the first instance, its strength was not found sufficient, and some upright supports were added; the alterations made are shown by the additional strength given to the ribs and platform above; and also by the diagonal braces of iron introduced in the outer divisions.

Pont du Jardin du Roi, at Paris, commenced in the year 1800, and finished six years afterwards, was designed by M. Lamande. It has five arches, resting on stone piers, 9 feet 10 inches in width, and 21 feet in height, above the level of the water. The arches are parts of circles, the chord of which is 105 feet, and the versed sine 10 feet. There are seven ribs at the distance of 7 feet apart, formed of a series of voussoirs, 4 feet 9 inches long, attached to each other by a number of wrought iron bolts.

The spandrils are filled with other frame-work, composed also of portions of circles, united by radiating and upright piers of iron: the principals are connected with rods of cast-iron. The timber frame, or platform, which covers this bridge is gravelled, and the footways are paved with stone.

After its construction, it was perceived that several of its parts near the abutments had yielded, and a considerable fracture was the consequence: this gave rise to many inquiries into the properties of the metal employed, and since that period other iron bridges have been constructed: but there is no treatise on the subject by the French engineers. Where stone abounds of such excellent quality, there seems to be no inclination to substitute iron for its use: and as that metal is not obtained at a very reasonable rate, it is not probable that it will be employed so generally as in England.

The iron bridges in which the principles of timber construction have been preferred to the introduction of the voussoirs, or the practice of the mason, are decidedly superior in effect: the experiments of Mr. Telford to form a suspended centre for his intended Menai Bridge gave rise to much of the constructions employed upon iron bridges in

France; and no one has done more to explain the principles defined in our examples than M. Dupin: there is yet wanting, however, such daring efforts as the Southwark Bridge; and there has been no attempt at the construction of an arch equal in span to those of

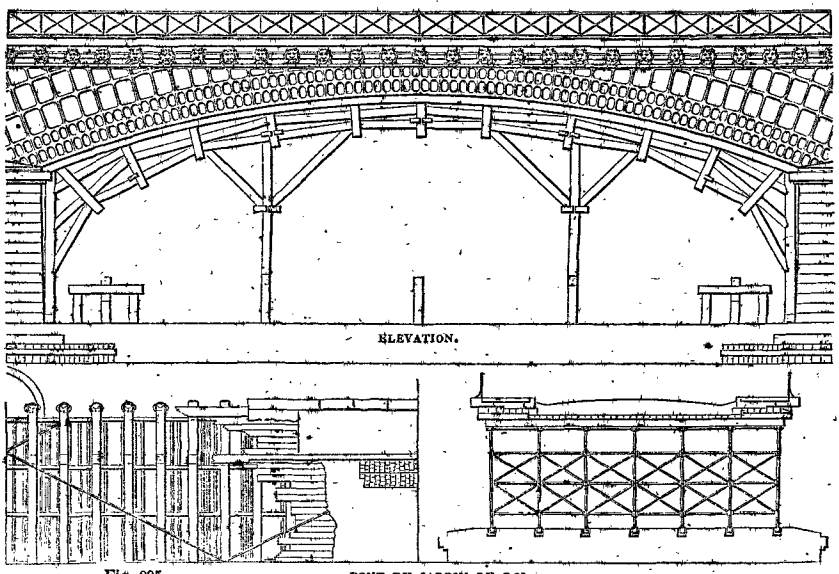


Fig. 295. PONT DU JARDIN DU ROI.

stone, and the state of the iron trade in France does not promise that much will be done with that material for the purposes of building.

After the bridge had been finished three years, its defective construction was apparent, and it became necessary to introduce a considerable addition of iron work to render it secure, and to prevent the effects that change of temperature had produced upon the several voussoirs.

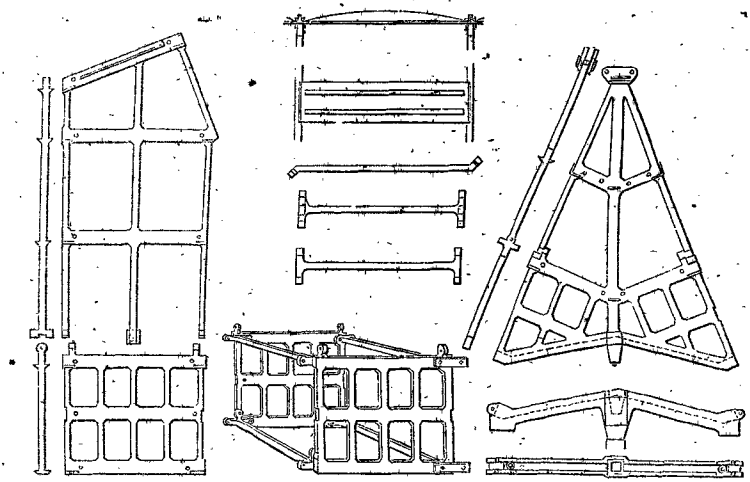


Fig. 296.

Pont on the Crou, near St. Denis, was built in 1808; its span is 39 feet 3 inches, and its versed sine 30 inches. It is composed of three principal ribs, a little more than 5 feet apart. About nine tons of iron were used in it, and the cost was 15,879 francs.

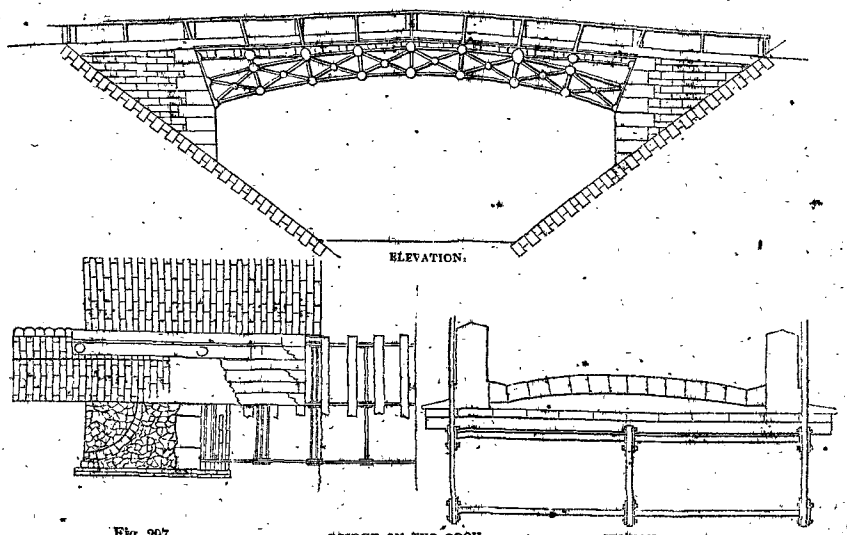


Fig. 297. BRIDGE ON THE CROU. SECTION.

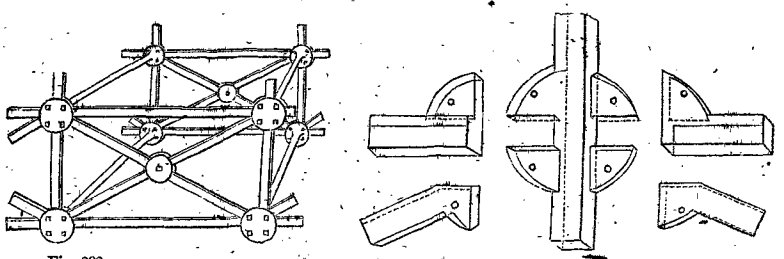


Fig. 298. BRIDGE ON THE CROU.

Supply of water. Aqueduct of Arcueil, near Paris; this ancient work was repaired in 1613, by Jacques de Mosse, at the command of Mary de Medicis, Queen of Henry IV., who required a better supply of water at the Luxembourg, which was collected from the neighbouring plains, and conducted by the aqueduct to the palace. Its length is nearly 1250 feet, and its breadth 11 feet 9 inches: it is strengthened at distances of 40 feet by buttresses, between which are nine arches, each 25 feet 7 inches span; the greatest height is 72 feet, and the whole construction, which is of squared stone, is most admirable.

The fountains which embellish the gardens and public squares at Paris require a great supply of water, and have always been distinguished for their taste; those of modern Italy can alone compare with them. The palaces of St. Cloud, Luxembourg, Palais Royal, Tuilleries, volumes of water are consumed for ornamental purposes, and serve to cool the atmosphere, and render it refreshing during the warm seasons, and at all times contribute to the beauty of the scene around: what in London is distributed for domestic comfort, is in France exhibited in artificial display.

The Cité d'Orleans, in the Rue St. Lazare, the writer constructed, and supplied from the Canal l'Ourq with water, laying on the same to the several houses in the manner practised in London, introducing at the same time other luxuries not then common in Paris. These, however, could not be rendered so efficient as in London, from the want of the public sewers. Generally, at that time, the houses were supplied by the water-carriers, who sought for it at the public fountains.

Aqueduct of Maintenon. This immense work was undertaken 1684, and abandoned in 1688. The levels and calculations were made by Lahire, and the project itself is Vauban's, who directed the construction; had it been finished, it would have surpassed in grandeur and magnificence all ancient or modern erections of the same kind.

It was to have formed part of a canal intended to bring water from the Eure at Pongoin to Versailles, a distance of nearly twenty-five leagues. The canal passed under ground in several places for a length of 4233 feet. The length of the aqueduct, which was in masonry, was 16,090 feet. It was to have presented five parts of different construction. First, 940 feet of 17 great arches, each 41 feet 8 inches in diameter, with piers 26 feet 7 inches thick, the greatest height 83 feet. Secondly; a length of 4815 feet 9 inches in two rows of arches, 70 in the lower row, 42 feet 8 inches span, and 140 in the upper, 18 feet 7 inches span, the piers 25 feet 7 inches thick, and the greatest height 135 feet. Thirdly; 3203 feet 8 inches in 3 tiers of arches, the first 47 arches, 42 feet 7 inches span, and 83 feet high, with piers 25 feet 6 inches thick, the height of the first row 97 feet 6 inches, of the second, 90 feet 6 inches. The third formed of little arches, two of which corresponded to one of the lower rows, its height was 46 feet 4 inches. The piers and buttresses were inclined. The canal supported by the third row was 7 feet 6 inches wide, and 4 feet 3 inches deep, with footways of 4 feet. The total height was 90 feet 6 inches. The breadth of the construction was 21 feet 4 inches at the impost of the arches of the third row, 30 feet 10 inches at that of the second, and 15 feet 1 inch at the first. Fourthly; 5377 feet 4 inches, of 77 lower arches similar to those of the second part. Fifthly; 575 feet 6 inches, of 11 arcades similar to the first portion. The different parts of the construction were to have been united by corkscrew staircases. The piers in the upper rows were pierced with arches.

Forty-seven arches on the first row of the third portion were constructed. The piers are built of very hard sandstone, and well put together. The interval is filled with masonry of rough work, which has decayed from the bad quality of the cement. The arches are mostly of brick, and, where care was not taken to carry the quoins through which strengthen the piers, this decay is most evident. The whole is in a far worse state than are many of the buildings of antiquity. Several rivers were rendered navigable, and a canal was dug for the purpose of transporting the materials; and it is said that 22,000,000 francs were expended in this useless work.

Aqueduct of Buc, near Versailles, was constructed to bring water from the plain of Sacle to Versailles. It consists of two rows of arches; the upper are nineteen in number; the lower range carries a bridge 13 feet 2 inches wide, over which the road crosses the valley, and is continued on a terrace of earth, so that the lower arches are entirely buried. The length is 1345 feet, and the height 42 feet 8 inches. The masonry of the piers is a kind of mill-stone, strengthened by quoins of squared stone. There are no buttresses, but their place is supplied by giving a great slope to the sides. The thickness of the piers is 13 feet 10 inches.

Aqueduct of Marly, is intended to conduct water from the Machine de Marly to Versailles, and begins at the reservoir, at the foot of which the machine is placed, and is 2113 feet in length; it consists of a single row of arches 25 feet 6 inches span. The piers are also 25 feet 6 inches wide; their thickness is 19 feet 2 inches below, and 6 feet 6 inches above. The greatest height of the aqueduct is 82 feet.

Abattoirs are buildings appropriated to the slaying of animals intended for food, collecting and cleansing the offal, and preparing the various substances which it yields, as glue, gelatine, oils, bone, hides, horn, &c.

It must be evident that nothing can be more injurious to health than allowing such operations to be carried on in densely crowded districts; no where in Europe is there so thorough a neglect of all sanitory considerations as in England; among the ancients, whom we profess to surpass in refinement, no slaughter-houses were permitted near the market where the meat was exposed for sale.

The Emperor Napoleon, about the year 1810, ordered five of these establishments to be commenced at Paris, and they were executed at the cost of the city. A commission was formed of five architects, assisted by the vice-president of the council of public works, the secretary, and a retired master butcher, named Combault, who were instructed to examine several plans that had been presented, and to report upon their efficiency; but eventually M. Gauché, one of the five architects, was commissioned to furnish the designs which were adopted.

The five abattoirs were those of Roule, Villejuif, Grenelle, Menilmontant, and Montmartre; their dimensions were defined by the number of persons that each district contained; the two first had each 32 slaughter-houses, that of Grenelle 48, Menilmontant and Montmartre each 64, making a total of 240.

To each of the abattoirs are attached houses for the melting of tallow; reservoirs and water laid on by lead pipes wherever required; every means for cleansing; stables, sheds, for the use of the butchers; inclosures for the cattle; and apartments for the superintendents. A vaulted sewer receives and carries away all superfluous water; there are also buildings for preparing tripe, trotters, &c. &c.

Scalding-house, used by the butchers for slaughtering. All the abattoirs have two or more ranges of these, each composed of two buildings divided by a yard. The stalls where the

beasts are knocked down are formed of walls of wrought stone, and are 16 feet wide, and 32 feet in length: each has two entrances, one in the yard, by which the animal enters, the other on the outer side, to permit the removal of the meat, &c. Each stall is provided with a supply of water for cleansing, with a drain, and a windlass and pulleys, by which the carcase can be drawn up to be flayed.

Two pieces of timber are placed across the building at 7 feet of height, fixed into the wall at one end, and carried or supported at the other by a stirrup iron: on these seven or eight carcases may be suspended, exposed to the air previous to their being taken to their several destinations. There are pegs and hooks around for the calves, sheep, and lambs.

The stalls, as well as the yard, are flagged with thick stones, the joints of which are filled with cement, that nothing offensive may pass through them. The bottom of the doors are cut, so that the air passes under them freely. The roofs project 3 feet beyond the external walls, which has the double advantage of sheltering the stalls from the sun's rays and forming a cover for the carts which remove the meat.

Sheds, for the oxen and sheep on their arrival, where they are housed previous to slaughtering: they are 9 feet in width in the interior; one side is occupied by oxen, the other by sheep, calves, &c. Large stone arches support a floor above, over which are separate divisions for the several butchers to stow away the forage belonging to them. Water is laid on for the use of the cattle.

Melting-houses, where the fat is converted into tallow.

Reservoirs. An abundant supply of water and facilities for distributing it is most essential in such establishments. In the five abattoirs in Paris 75,000 oxen are slaughtered in a year, and the mean quantity of water for the service is from 240 to 300 cube metres per day, to provide which there are two reservoirs to each, each containing 180 cube metres, formed in masonry, and lined with cement.

Keepers' Apartments. At the entrance of each abattoir are two small houses for the persons who have the charge of the establishment.

Stables and Sheds, &c. are provided for the carts and horses, commodiously arranged.

Sewers. These are most carefully constructed of a hard gritty sandstone: their dimensions are 3 feet in width and 6 feet in height; to prevent any smell from escaping, a trap is introduced, which answers admirably well: there are pits for the dung, which is removed every day. No towns of any importance on the Continent are without these establishments, as Mantua, Lyons, Blois, Rochefort, La Rochelle, Grenoble, Brussels, Orleans. Those at Strasburgh, Marseilles, Vicenza, &c., are of considerable extent.

Markets. The great points to be considered in these establishments are position, solidity, convenience, and health, and in Paris it was decided that their situation should be within the reach of the greater portion of the population of the district.

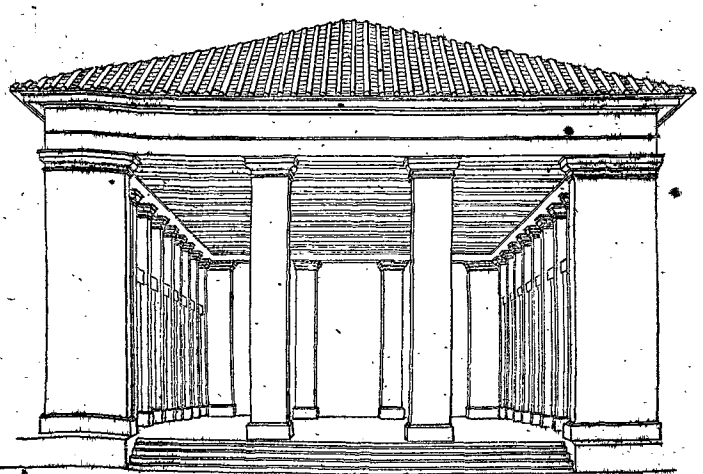


Fig. 299. MARKET.

The strength requisite for an edifice is particularly required in one intended for the public service, and where the slightest accident might be of great importance.

Convenience and salubrity require that all who attend should be sheltered from the

inclemency of the weather; that the arrangements should be suitable for the provisions bought and sold; every possible means adopted for thorough ventilation, and every precaution taken to maintain the most perfect cleanliness.

The walls of a market should be carried up to a certain height in masonry or brickwork: the lower openings should be provided with Louvre boards, to exclude the sun, rain, and wind, without too much shutting out the light and air. Other openings must be provided under and in the roof, to afford additional light and air.

A certain width should be given to the markets, so as not to increase the extent of the outer walls; and pillars internally should not be introduced, as they obstruct and occupy room; where they are indispensible they should be of stone or iron, and placed as distant from each other as possible.

The width of the building depends upon the number of stalls, which should be in pairs, so that one walk approaches two rows.

Experience proves 6 feet 6 inches a sufficient width for the walk, and the same for the stalls: hence a market may be in width from 6 to 7 metres, from 12 to 13, and from 18 to 20.

The four new markets constructed at Paris, of stone, are of these dimensions.

A public fountain is indispensible, and constitutes one of the chief ornaments.

The architecture should be simple, yet imposing from the mass, the arrangement, and the proportions.

The divisions should be so arranged that all parts should be equally eligible without any just grounds for preference; nothing should be sold out of the enclosure, that the entrances and streets leading to it may be free from all obstructions. The whole should be shut at night. When the market is of any extent certain accessories are requisite, as vaults, &c., for warehousing unsold goods. The market at Naples is a large square, with a semicircular termination on one side: the butchers' stalls are arranged around it. Those at Florence, Bologna, and Rimini are admirably contrived, and answer their purpose effectually.

Marché Saint Gervais was built to supply the place of another, which was not open, in the

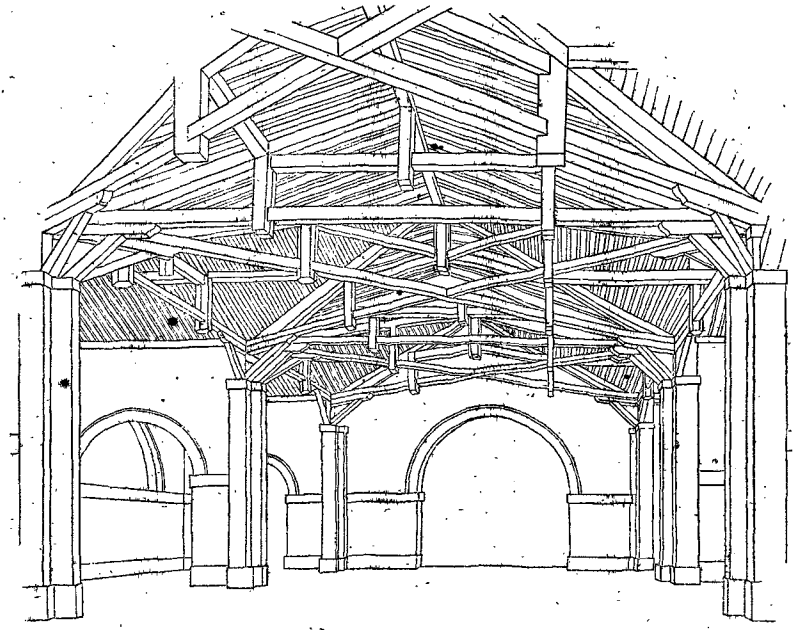


Fig 300. ROOF OF A MARKET.

Place St. Jean. It was originally intended to have had stalls for the use of those who attended; but such divisions being found destructive of the good effect and an impediment to that free intercourse so necessary for those who attended, the idea was abandoned.

M. Labarre was the architect, and the structure is in every way highly commendable, being well ventilated, and affording convenient and easy access on all sides.

The markets first established were held in an open square, or in the streets, and it was not until about the latter end of the last century that any were covered in: the advantages derived by all that attended were so great, that Napoleon ordered arrangements to be made for erecting structures which should exclude the inclemencies of the weather, and be convenient to both buyer and seller. Paris set the example to other great communities, and hence an important and beneficial change has been effected in these establishments throughout Europe.

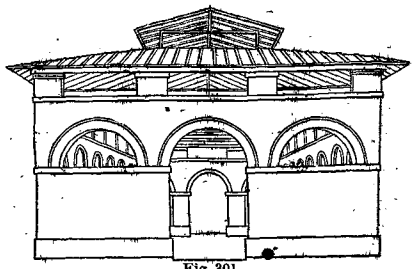


Fig. 301.

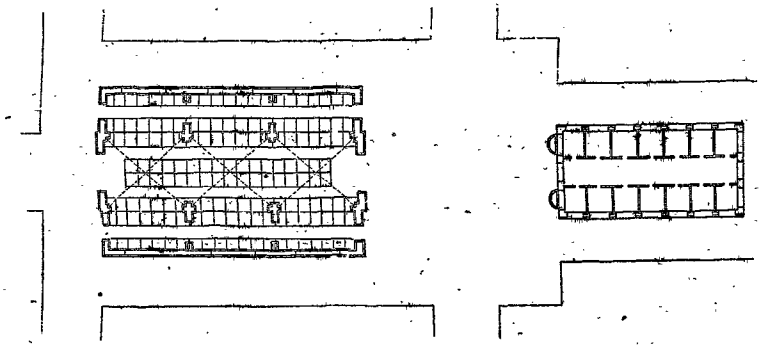


Fig. 302. MARKETS.

Marché Saint Martin was rebuilt on an ancient site between the Rues St. Denis and St. Martin, a few years since, and is an admirable example of its kind. It entirely covers the garden of the old convent, now appropriated to the reception of various models, and known as the Conservatoire des Arts et des Metiers.

The garden was bounded on three sides by the convent walls, affording a favourable situation for a market. M. Peyre, the architect, was instructed to design a suitable structure, which being approved was carried up under his superintendence.

Marché Saint Germain was erected from the designs and under the superintendence of M. Blondel, and is the most important in Paris.

Other smaller markets have been established in imitation of that at Florence, in various parts of the city, and in most of the towns throughout France. Great taste has been displayed in these structures, and the manner in which they are covered is highly creditable to the engineers, who have displayed a thorough knowledge of ventilation. They are therefore peculiarly worthy of our attentive study.

Every large town in France has its market, conveniently situated, and of dimensions proportionate to the number of its inhabitants. Vegetables, fish, meat, flowers, all have either a portion set apart, or a building devoted entirely to them. The timber roofs, and in some instances iron, span the entire area; and, when covered with ornamental tiles, produce an elegant effect; they are always lofty, well ventilated, and sufficiently supplied with water. Italy seems to have afforded the model for most of these structures; arches resting on columns, with a simple and bold projecting cornice, all kept within the laws of proportion, constitute their ordinary design. Their entire area is paved, and, mounted upon a bold plinth, are easily cleansed.

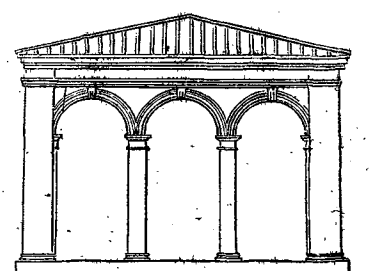
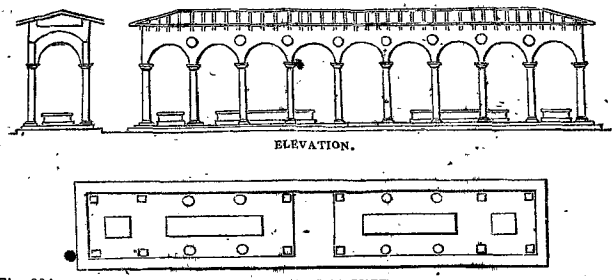


Fig. 303. MARKET.



ELEVATION.

PLAN OF MARKET.

Fig. 304.

The Bourse at Paris, erected from the designs of M. Brogniart, and completed by M. Labarre, is a fine model for an exchange, where the public business of a large com-

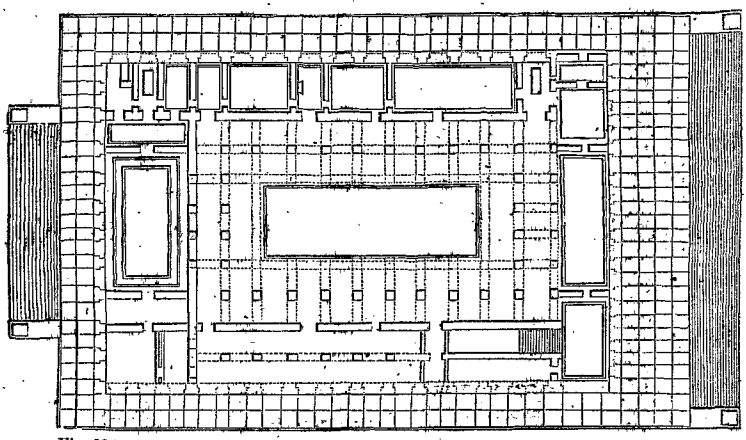


Fig. 305. PLAN OF BOURSE.

mercial city is to be carried on. The external character is that of a Greek temple, having fourteen columns at each end, and twenty at the sides. In the middle is a covered court,

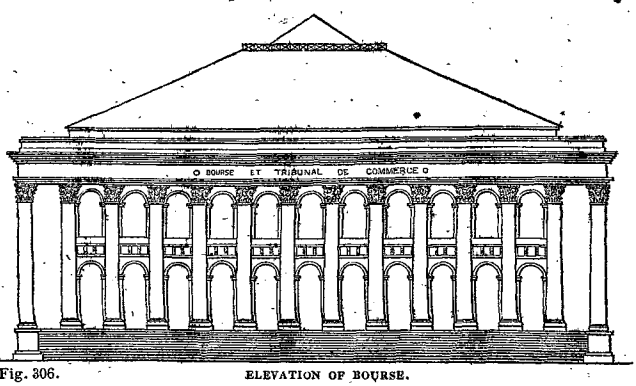


Fig. 306. ELEVATION OF BOURSE.

where the merchants congregate, and around are a variety of apartments devoted to their especial use: on the floor above, the several tribunals connected with commerce are held.

The roof is of iron, ingeniously contrived to support the skylight of the great court.

There is throughout great simplicity in the arrangements, and beauty of proportion in the architecture, with a sufficient quantity of decoration.

The plan, section, and elevation explain its character and proportion: it is executed with a hard and durable stone, in a most admirable manner. Its length is 212 feet, and width 128 feet. The roof is formed entirely of iron and copper, and the court or area occupied by the merchants is 116 feet long and 76 feet broad, and it is calculated will contain 2000

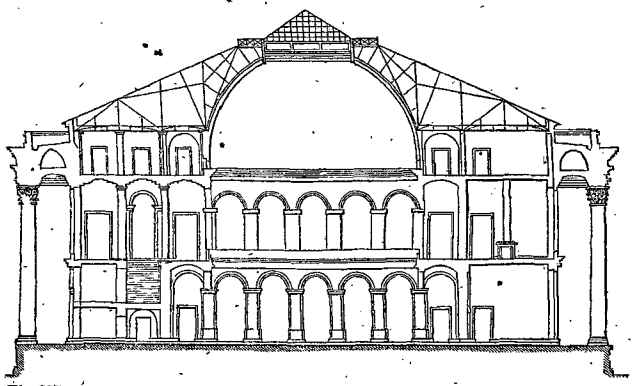


Fig. 307. SECTION OF BOURSE.

persons. The agens de change, or brokers, have a portion railed off for their especial accommodation; and around the great court are the tribunal and chamber of commerce, the court of bankruptcy, and several other halls for the convenience of the merchants and others, and the cost was upwards of 300,000*l.* sterling.

The exchange marks the importance of a city, and should always be erected in the midst of the most thronged part, and rendered capable of receiving not only the native, but all foreign merchants who attend: in its architecture we expect to find that the best talent the country can produce has been employed, and certainly in this example we are not disappointed.

Artesian wells have long existed in Italy, in Austria, in the Crimea, Siberia, Sahara, Palmyra, Balbec, Tyre, and Egypt; their modern name arises from their having been immemorially used in Artois, one of the departments in France. Belidor mentions one in 1749 at the monastery of St. André, near to Aire, and in the ancient convent of the Chartreux, at Lillier, in the same neighbourhood, is another more than 700 years old.

About the year 1824, M. Péligot, one of the superintendents of the hospitals at Paris, suggested the idea of sinking a well upon the Artesian principle, and workmen were sent from Artois for the purpose; whilst this was being effected, M. Mulot, a smith, became interested in the operation, and turned his attention to the subject; he was consequently employed by the Marchioness de Groslier to sink one at Epinay; success attended his efforts, and he was nominated to attempt one at Grenelle. The primitive soils, according to M. Arago, are but rarely stratified, or are found in regular beds. The fissures in granitic rocks, the crevices separating the contiguous masses, have but little width or depth, and do not frequently communicate with each other; in such soils the waters of filtration have but limited outlets, each film or thread terminating its course alone, without receiving any increase from others in their descent. The springs being numerous in the neighbourhood, it was not thought probable that any vast quantity of water could be obtained, as the whole of the rain penetrating the earth was supposed to pass off through various openings in the sides of the hills.

The secondary soils, which are composed of a variety of rocks, in general take the form of immense reservoirs or basins, the centre being considerably depressed, or the extreme boundaries of it greatly elevated; within this basin hills, and often mountains, arise, apparently destroying its original character. The stratification of the secondary formation is in regular beds, some of which are of enormous thickness, composed of sand or grit, and very permeable; these permeable beds, as they rise towards the extremities of the basin, become bare on the sides of the mountains and hills. The rain water which falls on the earth, after penetrating it, forms one continued sheet, which pursues its course with great rapidity when the beds have a great declivity, and, reaching the lowest point, is accumulated in vast quantities. One chalky or calcareous stratum, which is furrowed out in all directions, and particularly in the upper portion, allows the pluvial water to pass with great facility, and also to circulate through the mass to a great depth: and in this peculiar stratum the wells both of Grenelle and Rouen have been bored.

The tertiary soils are stratified, and composed of many beds placed over each other, and

separated by clean and well defined joints, like the secondary on which they rest; these basins are of less extent, and derive their form from the rectifying of the beds, the elements of which they are constituted being the same as those found on the neighbouring hills; the several beds are arranged in a regular manner, and their separation is formed by a layer of sand, through which the water freely percolates; in these several sandy fissures it acquires force as it descends, and at great depths, its pressure being augmented, the flow is rendered constant.

These soils are undoubtedly the best for sinking Artesian wells, because they have at their base courses of sand lying on impermeable clays, and are less subject to dislocation or rupture than rocks of the older formation. Such strata are easily examined, and are usually found rising from the centre of the basin, and following an inverse direction to that of the inclination of the water, which like a subterranean river pursues a downward course till it meets with an outlet. They frequently become broken when the water they contain weeps into small rivulets, and is carried away on the surface.

Where the well has been bored at Grenelle, the upper stratum or tertiary deposit is 41 metres in thickness; the next is composed of chalk mixed with flint, 99 metres; then a grey chalk, without any silex, 25 metres; to this succeeded a grey chalk, in which were iron pyrites, 341 metres; then a wealden clay, grey sand, and a sandy clay, in which were found ammonites and other fossils; the whole depth bored through being 548 metres, or about 1798 feet.

The work was commenced on the 30th of November, 1833, by M. Mulot, and water was obtained in February, 1844, at an expense of 303,000 francs.

The railroads of France, Belgium, and Germany are progressing, and will probably become the only communications between the various towns and cities of the continent; and in a few years the diligence and post carriage will only be remembered as ancient modes of conveyance. The railroads already laid down in Belgium and Prussia are worked in an admirable manner, and at far less cost than those of England; the engineering difficulties overcome beyond Liege, on the way to Cologne, the cutting and tunnelling and completing the lines, rival any that have been hitherto executed. The greater part has been done by the government: as most of the rails, carriages, and machinery employed upon these undertakings were first sent from England, no particular description of them is required; and although the several foreign governments have established manufactories of their own, most of them are provided with models and workmen from this country.

When the whole of the lines projected are completed, it will be a highly interesting task for the engineer to draw up an account of their difficulties and cost, and compare them with what has been performed during the same period of time at home.

Of the continental railways completed, first may be cited those in France: that of St. Germains, 11¾ miles in length; Versailles, the right bank, 14 miles; the left bank 10¼ miles; the Strasbourg, which is open from the Rhine to Switzerland, 87 miles; Paris and Orleans, 82 miles; Paris and Rouen, 84 miles; Rouen and Havre, 57 miles; Montpellier and Cette, 16⅔ miles; Mulhausen and Tham, 11¾ miles; St. Stevens and Lyons, 31 miles, and many others are in progress.

Of the Belgian railroads complete, there is the north line, from Brussels to Antwerp, 27¼ miles; west line, Malines to Ostend, 76¼ miles; east line, Malines to the Prussian frontier, 82⅔ miles; south line, Brussels to the French frontier, 51 miles; Ghent to the French frontier and Tournay, 48 miles; and Braine la Compte to Namur, 41 miles.

The whole 326¼ miles cost about 4,114,354*l.*, or 12,611*l.* per mile.

Among the German lines opened may be mentioned the Leipzig and Dresden, in length 71½ miles; Leipzig and Magdeburg, 72 miles; Berlin and Potsdam, 18 miles; Berlin and Stettin, 89 miles; Berlin and Frankfort on the Oder, 48 miles; Altona and Kiel, 63 miles; Brunswick and Oschersleben, 30 miles; Brunswick and Hanover, 40 miles; Cologne and Aix-la-Chapelle, 54 miles; Cologne and Bonn, 20 miles; Dusseldorf and Elberfeld, 17 miles; Frankfort and Wiesbaden, 26 miles; Manheim, Carlsruhe, and Kiel, 70 miles; Nuremberg and Furth, 5 miles; Vienna and Gloggnitz, 53 miles; Breslau and Friburg, 40 miles; Budweis and Gemunden, 120 miles; and several others of great extent, nearly ready to be opened, and in progress.

CHAP. VII.

ENGINEERING IN THE UNITED STATES OF AMERICA.

United States. Of late years there have been some extensive engineering works practised throughout this country which bid fair to rival those of the Old Continent. Admirably adapted for commerce, its enterprising population are exerting every effort to improve its harbours, internal navigation, and railroad communication.

The rivers are noble and important, being navigable to a considerable height, intersecting the country in all directions, and forming deep bays at their mouths. The Hudson for 160 miles will admit vessels of 80 tons, and the Susquehannah, the Potowmac, the Delaware, are all valuable as the means of internal navigation, as are the Catahouche and the Alabama, which both fall into the Gulf of Mexico.

The Mississippi rises in the latitude of 47° north, and flows south across 18 degrees of latitude, through a course of 2000 miles. About half way from its source it receives the Missouri, a larger river, which has a course of 2300 miles. Other noble rivers offer every facility to trade and commerce; it has been estimated that the inland navigation amounts to upwards of 23,000 miles, and the basin of this great system of rivers is computed to contain 1,099,000 square miles.

Timber, from its abundance, is generally used in the construction of quays, docks, and railroads throughout America; and we are indebted to their engineers for some admirable applications of this material to bridges, &c., which are noticed in our account of carpentry.

It is not possible to give more than a brief outline of some of their leading works, which are increasing rapidly over the whole extent of their vast territory.

The harbours of America are mostly capable of receiving the largest class of vessels, and are all connected by means of inland navigation with the principal towns. In Canada are the harbours of Quebec, Halifax, and Montreal; and in the United States the chief are Boston, New York, Philadelphia, Baltimore, Charles Town, and New Orleans, all of which possess great natural advantages, and afford well-sheltered anchorages in deep water.

Quebec, the capital of Canada, is situated on the St. Lawrence, about 340 miles from its mouth. The harbour lies between the town and the island of Orleans, and is very commodious, the water being about 28 fathoms deep, with a tide rising from 17 to 18 feet, and at springs from 23 to 25 feet. It is protected by a citadel built on the headland, called Cape Diamond, 345 feet above the level of the sea; the fortifications are very strong. In 1812 the first steamboat that plied on the St. Lawrence was launched at Quebec, and now the line of steam navigation extends from the Atlantic to Amhurstburg, a distance of more than 1500 miles Quebec commands the whole of this internal navigation, which can only be carried on between April and November, in consequence of the frozen state of the rivers, large masses of floating ice being kept in constant motion by the tide.

Halifax is the capital of Nova Scotia: the harbour, one of the finest in America, can be entered at all times, being rarely impeded by ice. There is a very extensive dockyard, and the port is the seat of a considerable fishery. The town is situated on a peninsula on the west side of Chebucto Bay.

Boston, one of the largest towns in New England, is the capital of Massachussetts: it is situated on a peninsula near the bottom of a large and deep bay; it is united to the mainland towards the south, by a narrow isthmus called the Neck. Charlestown lies on the north side of the bay, and Dorchester on the south, with both which places Boston communicates by means of extensive wooden bridges: the bay containing upward of 75 square miles, and studded with many islands; it extends along 50 miles of coast, between Cape Ann and Cape Cod. The harbour at its mouth is confined between two necks of land, which allow but a narrow passage from the Atlantic.

The quays are simply constructed of earth and timber. A row of piles driven close together forms the face of the quay, secured perpendicularly by walings bolted on to the face of the quay, and running throughout its whole extent; diagonal ties are made fast to the insides of the piles, and large pieces of timber, connected with the facing piles, are laid behind them, which being embedded as well as the braces by the earth filled in, the whole is rendered tolerably solid; these diagonal timbers serve the double purpose of struts and ties, and operate against any lateral pressure to which the quay may be subjected. The filling in with earth is continued to a level of about 5 feet above the ordinary spring tides;

at that height the heads of the piles are cut off level, and the platform of the quay is covered with planking. The whole of these works are executed with unsquared timber, and are neither painted nor covered with pitch or tar.

On some of the quays which extend for a considerable distance into the harbour, rows of warehouses are constructed.

At Boston are the only graving docks which belong to the government of the United States: one is in length 341 feet, in breadth 80 feet; the depth of water is 30 feet, but the fall of the tide being only 13 feet, 17 feet are pumped out by means of a steam-engine whenever a vessel is admitted for repair. These docks are constructed in an admirable manner in granite, at an expense of upwards of 150,000*l.* each. They were executed under the able direction of Mr. Baldwin, the government engineer.

To connect some portions of the neighbourhood of Boston as well as to form a large basin, an embankment of earth 8000 feet in length has been thrown up, confined between two stone walls; and the water contained in the basin is made to turn machinery connected with some manufactories.

New York, the capital of that state, is situated on the southern extremity of Manhattan Island, at the point of confluence of the Hudson with the east river. The inner bay is perhaps the finest in the world: it is completely land-locked, and affords excellent anchorage; the entrance through the narrows is very beautiful and picturesque, the shore being studded with trees down to the water's edge, mixed with farms, cottages, and villas.

From New York to the Bar between Sandy Nook Point and Schryers Island, which separates the outer harbour from the Atlantic, is 17 miles.

The tide flows up the Hudson for 160 miles above New York as far as Troy, and these natural advantages have been further improved by an extensive system of canals, which connect with the Lakes Erie and Ontario. One omission has, however, rendered this beautiful harbour a source of serious evil; from there not being any sewers in the town, the harbour becomes the receptacle of every impurity, and fevers of the worst kind are the constant results of the effluvia.

There are screw and hydraulic docks; the latter are worked with a Bramah's press, and by means of a timber platform, swung between two frames, the loaded vessels are lifted above the water. Twenty chains or more, on each side of the timber platforms, pass over iron pulleys supported above, and the platform bearing the vessel rises by the injection of water with a cast-iron cylinder attached, which moves a horizontal beam fastened to the suspended chains.

The cylinder and ram are surrounded by masonry, and rendered perfectly stable; the external diameter of the cylinder is 28 inches, its internal 12 inches, and that of the ram which works it 11 inches, and 10 feet in length, which has a power sufficient to raise a vessel of 800 tons. The water is injected into the cylinder by a steam-engine of high pressure and six horse power; when the vessel is to be lowered, it is merely necessary to let the water escape slowly from the cylinder, and the platform gradually descends.

Philadelphia is the city and sea-port of the state so named, and is at the conflux of the Delaware and Schuylkill. Vessels of the largest burthen ascend the river as far as Newcastle, but those drawing 18 or 20 feet water cannot reach Philadelphia, in consequence of a bar a little below the city. The harbour is a vast arm of the sea, navigable for 100 miles from the Atlantic.

Baltimore, a city of Maryland, is on the north side of the Patapsco river, about fourteen miles above its entrance into the Bay of Chesapeake. The harbour is a fine expanse of water, and capable of containing upwards of 2000 vessels.

Charlestown in South Carolina, is built upon a point of land between the Ashley and Cooper rivers; the harbour is spacious and convenient, but the entrance has many sand-banks. The depth of water on the shallowest part of the bar at ebb-tide is 12 feet, and at flood from 17 to 18 feet; whilst in the middle channel at low water, it does not exceed 9 feet. A lighthouse has been erected 80 feet in height, with a revolving light.

New Orleans is situated on the eastern bank of the great Mississippi, about 105 miles from its mouth; the depth of water opposite the city is about 70 feet, but the ebb and flow of the tide do not extend to it.

The Canals in the United States exceed in length more than 3000 miles; wherever internal navigation cannot be obtained by the removal of obstructions in the great rivers, an artificial cut is introduced; no labour has been spared to render water conveyance complete. Many of the canals are carried over wide rivers on timber viaducts, and often pass for miles through dense uninhabited forests. Some are so wide and deep as to admit the passage of steamers through them. By one the Gulf of Mexico is united to the Mississippi and St. Lawrence: a river and canal navigation extends from New York to New Orleans, a distance of upwards of 2700 miles, 672 of which are by the Erie and Ohio canals.

The Erie Canal is one of the most important in the United States; its entire length is 363 miles; after leaving Albany, it passes along the right banks of the Hudson and Mohawk rivers, crossing the latter at Middleton: it then continues its course for twelve miles on

the north bank of the Mohawk, and by the upper aqueduct again crosses it, and is carried along the southern bank to Utica, distant from Albany 108 miles; still winding along the southern bank of the Mohawk, another 160 miles, it arrives at Rochester, where by means of an aqueduct it crosses the Genesee. This aqueduct, formed of eleven arches of hewn stone is 804 feet in length.

The canal after leaving Rochester runs in a westerly direction towards Lockport, a distance of 63 miles, where it ascends the mountain ridge by five double combined locks, each rising 12 feet 6 inches; at Pendleton, which is nine miles farther, it enters Tonnewanda Creek, and twelve miles beyond, this magnificent canal terminates at Buffalo.

The breadth at top is 40 feet, at bottom 28 feet, and its depth 4 feet. On the main line are eighty-four locks, 90 feet in length, and 15 feet in width; the total lockage being 688 feet. There are eight feeders, eighteen aqueducts. From Buffalo to Rochester the fall is 4 feet; then a rise of 680 feet, and again a fall of 62 feet; the total rise and fall being 692 feet.

One of the aqueducts which crosses the Mohawk is 1188 feet in length, and the great embankment between Palmyra and Pittsford, about 245 miles from Albany, is 72 feet in height.

Albany, in the state of New York, is situated on the right bank of the Hudson; and in order to improve the navigation above the town, a dam 1100 feet in length, and 9 feet in height, has been erected across the river; the lock united with it is in length 115 feet, and in breadth 30 feet. Albany is the great depôt, and the vessels which navigate the canal are received in a large basin, the area of which is about thirty-two acres. This basin is formed by a mound of earth, 4300 feet in length, and 80 feet in breadth at the base, thrown up in a line with the Hudson, for the purpose of shutting in a part of its waters. The lower end of the bank is unconnected with the shore, a passage being left for the vessels to pass; and the upper end is usually closed, in order to prevent the floating ice from entering and injuring the vessels within; but there are means for allowing the passage of the water at the upper end which acts as a cleanser, by driving the mud before it. On the top of the earthen embankment are erected the warehouses, and around it is constructed a timber wharf for the vessels to load and discharge their freights. Great improvements have recently been made on the canal, which was commenced in the year 1817: it has been in many parts increased in width, and deepened. A new aqueduct has been erected over the Genesee river at Rochester, which is 858 feet in length, and 28 feet in height from the base of the piers to the top of the parapets. It has seven arches 52 feet span, and the six piers and two abutments on each are 10 feet in thickness.

The width at the base is 75 feet 6 inches, and at the coping 67 feet 8 inches. The clear width of the water-way is 45 feet, which allows for a double boatway.

The old locks, which were of timber, have been replaced by those of stone: the cutting through the rock at Lockport extends 2½ miles, for a width of 62 feet, with vertical sides.

From the Erie canal branches off the Champlain, the Chenango, the Black River, the Oswego, the Cayuga and Seneca, the Crooked Lake, the Chemung, and the Genesee Valley.

The Champlain Canal commences 9 miles from Albany, and is 11 miles in length, besides a river navigation of 76 miles; the width at top is 40 feet, at bottom 28 feet, and the depth 4 feet. There are 21 locks, each 90 feet in length, and 14 feet in width; the total rise is 134 feet, the fall 54 feet, the lockage being 188 feet.

Chenango Canal is in length 97 miles, its rise from Utica is 706 feet, its fall 303 feet. The total lockage is 1009 feet; there are 116 lifts, and one guard lock; five are of stone, and the others of stone faced with timber. There are 19 aqueducts, 52 culverts, 2¼ waste weirs, 56 road and 106 occupation bridges, 53 feeder aqueducts, 12 dams, and 7 reservoirs.

The Black River Canal is a succession of slack water pools and canals, and the total length of its navigation is 85 miles; the ascent and descent from Rome to Carthage is 1078 feet.

The Oswego Canal is of a similar kind, and its length is 38 miles: there are 14 locks constructed of stone, and 6 guard locks, which are in length 90 feet, and breadth 17 feet; the total descent is 123 feet.

The Cayuga and Seneca Canal is 23 miles in length, and has eleven locks, descending 73 feet.

The Crooked Lake Canal is 7¾ miles in length, and has twenty-seven lift and one guard lock, built of timbers; the total lockage being 269 feet.

The Chemung Canal is in length 23 miles, and has one guard lock and 52 lift locks of timber, which accomplish an ascent and descent of 516 feet; there are 76 bridges, 5 culverts, and 3 aqueducts.

The Genesee Valley Canal, for the first 36 miles after leaving Rochester, passes through a rich low country, and then rises 95 feet by means of 10 locks. On leaving Mount Norris, it passes through a natural and precipitous rocky defile, upwards of 400 feet in depth;

there are then numerous locks, and a tunnel. The summit level is 978 feet above Lake Erie, and 1546 feet above high water; the total lockage is 1063 feet.

The Ohio Canal extends from Portsmouth to Cleveland, a distance of 307 miles, and the summit level is 499 feet above the Ohio at Portsmouth, 405 feet above the waters of Lake Erie, and 973 feet above the Atlantic Ocean. The whole district comprised by the Illinois, Indiana, Ohio, and Michigan states, is highly favourable for the construction of canals, as there are few natural impediments. The Ohio valley is one extensive inclined plane, watered by numerous streams; the hills which are cut through are generally either lime or sandstone mixed with mineral coal.

The Ohio valley is divided by the river which flows in a deep ravine, and is in length from the city of Pittsburg to the Mississippi, in a straight line, 548 miles, but measured by its windings 948 miles. The height of the hills at Pittsburgh is about 1290 feet above the level of the sea.

The length of the Mississippi river below the point where the Ohio falls into it is 1100 miles, and, allowing 3¼ inches fall per mile, we shall have 321 feet for the elevation of the spot where the junction of the two rivers takes place. The whole valley of the Ohio was at one time a dense forest, the central plain excepted, which, as far as the sources of the Muskingum, was an open savannah covered with grass.

Lake Erie is said to be 565 feet above the surface of the Gulf of Mexico, and Pittsburgh, which is 747 feet above the same gulf, is also 830 feet above the tide water in the Atlantic bays of Chesapeake, Delaware, Hudson, and St. Lawrence. Pittsburgh is therefore 265 feet above Lake Erie, and distant from it in a straight line 106 miles, and it has been supposed, that if a channel could be cut from the Ohio at Pittsburgh to the lake, the rivers Allegany and Monongahela would, instead of flowing into the gulf of Mexico, rush into the Lake Erie, with a fall of 265 feet in 105 miles, or at the rate of 2½ feet per mile.

It is a curious fact, that the Allegany river should have its source within 5 miles of the Lake Erie, and after winding from thence 200 miles should then be 265 feet above the surface of the lake, while the Ohio does not sink in its course to the level of the lake, until it arrives at Marietta.

At the surface of the Mississippi, immediately at the mouth of the Ohio, the level is 321 feet above the Gulf of Mexico. Lake Michigan is 35 feet higher than Lake Erie, or 600 feet above the level of high water in the Atlantic.

The Illinois river, which runs from the Lake Michigan, resembles in its course a winding canal, there being only a fall of 279 feet in the distance of 520 miles, where it unites with the Ohio, which is about 6 inches in a mile.

The valley of the Ohio, as well as that of the river Allegany, is in its inclination remarkably gentle; from Olean, in the county of Cataraugus, to the Mississippi, a distance of 1148 miles, there are no natural impediments in the way of navigation, except those which occur at the rapids of Louisville.

The Monongahela is more rapid, and the Tennessee and Kanaidha, which rise on the high table land of Allegany, 2000 feet above the level of the sea, are very rapid in their course, and impeded by many falls.

The Ohio canal has been admirably executed, and has a lockage of 1185 feet, which is overcome by 152 locks; the width of the canal at top is 40 feet, and the depth 4 feet.

The canals in the United States are usually constructed on the principle of utility alone, little attention being paid to minutiæ; their embankments are seldom dressed evenly or turfed, and timber being exceedingly abundant and easily obtained, it has been used even for the construction of locks; where, however, these have shown decay, stone has been substituted, and more finish is given in the general arrangements.

Delaware and Raritan Canal, in the state of New Jersey, is in length 42 miles; it is 75 feet in width at the surface, 7 feet in depth, and has 14 locks, each 100 feet in length, by 24 feet, besides a tide lock at New Brunswick; the total lockage being 116 feet; there are 17 culverts, 29 bridges, and 1 aqueduct.

This canal is supplied with water by a feeder 23 miles in length, and between 50 and 60 feet in width, and 6 feet in depth. Its fall is 2 inches in a mile, and has 1 lift and 2 guard locks; there are 37 bridges, and 15 culverts.

Morris Canal, in the same state, commences at New Jersey, and is in length 101¾ miles; its ascent is 915 feet, and descent 759 feet, making a total rise and fall of 1674 feet, which is principally overcome by inclined planes, ingeniously contrived to convey the boats from one level to another. At each end of these is a lock, in which the boat is adjusted for its ascent, and another at the top, to elevate it to the level above; when adjusted, the whole is drawn up by means of machinery, which serves also to lower the boats in their downward passage.

The elevation at Easton is 161 feet, and summit level 915 feet above the Atlantic.

The width of the canal is 32 feet at top, 20 feet at bottom, and 4 feet deep; the boats which navigate it are about 70 feet in length, and 8 feet 6 inches in breadth across the beam; their freight is usually about 30 tons; they are drawn up the inclined planes by

being first placed upon a timber carriage, which has beneath it, at each extremity, an iron truck, running upon four wheels, working upon iron rails laid down on the inclined planes.

When the boats are placed with their load upon the timber carriage, they are prevented from falling sideways by a piece of trussed vertical framing, which is coupled at top by means of chains. The railway extending for some distance into the canal, the carriage is made to pass under the boat with great facility; when secured, the machinery put in motion, the whole is drawn by a chain up the inclined plane, to the lock prepared to receive it, which has gates at each end; after the boat is deposited, one pair is shut and the other opened, when the water being admitted, it is floated off the car, and continues its course along the canal. A boat going in the opposite direction is let down into the lock, passed down the inclined plane, and on its arrival at the lower canal is floated in a similar manner. There are in all twenty-two of these inclined planes, and the machinery to work them is admirably contrived to effect the object, without subjecting the boats to any material injury; their average inclination is two in twenty-one. There are 4 guard locks, 5 dams, 30 culverts, and 12 aqueducts, including one of stone at the little falls of Passaic, which has an arch of 80 feet span, and another of wood over the river Pompton, which is 236 feet in length, and is supported by nine stone piers; there are also 200 bridges of different descriptions.

The central division of the Pennsylvania canal forms with the Columbia and Portage railroad the great chain of communication between the Delaware and Ohio rivers. Its length is 172 miles, and its total lockage 670 feet 6 inches. Its width at the top is 40 feet and at bottom 28 feet; the depth being 4 feet. There are 18 dams, 33 aqueducts, 108 locks, besides the two guard and outlet locks at Columbia. The locks are 90 feet in length and 17 feet in width.

The western division is in length 104¼ miles, 21 miles or more consisting of slack water navigation. The canal is in width 40 feet at top, 28 feet at bottom, and 4 feet deep. Its lockage is 471 feet, which is performed by 66 locks 90 feet by 15 feet within the chamber. The average fall is about 8 feet per mile, from Johnstown to Blairsville, and from thence to Pittsburg about 3 feet.

There are two tunnels, 64 culverts, 39 waste-weirs, and 152 bridges.

By this line the route by railroads and canals is complete to Pittsburg, and is the great thoroughfare from Philadelphia into the west; the entire distance which can be performed by it is 394½ miles.

Schuylkill navigation is a succession of canals and pools extending from the dam of Fairmount, near Philadelphia, to Port Carbon, in the county of Schuylkill. The length by the canals is 58 miles, and by pools 50 miles. The canals are 36 feet wide at top, 22 feet at bottom, and 3 feet 6 inches in depth. There are 129 locks, 80 feet in length and 17 feet in width; 34 dams, and one tunnel 385 feet in length.

It is not possible within our limits to enumerate the whole of the canals in the United States; they are mostly on the same construction, and executed in a similar manner to those we have described.

The cost of a canal depends, as in all other countries, upon the nature of the soil and climate, the price of labour and provisions, as well as other local circumstances.

The excavation of a prism, 3 feet in depth throughout, where the soil is either sand or gravel costs about six cents per cubic yard, and for clay or stony matter eleven cents. Excavation of loose rock costs fifty cents, and of solid rock a dollar per cubic yard, the dollar being worth about 4*s.* 3*d.*, and the cent a hundredth part; the cost of embankment is a little more.

It has been found that the resistance to boats 13 feet 6 inches wide, and 3 feet draft, in a canal 60 feet wide and 6 feet deep, is 81½ pounds. In a canal 48 feet wide and 5 feet deep, 100 pounds; and in one 40 feet wide and 4 deep, 130 pounds, and that 18 per cent more can be transported by the same power on the former than on the latter canal.

The canals of the United States are usually 4 feet in depth; the inner slopes are 1½ to 1, the outer 1½ to 1; the towing bank is 10 feet wide at top, and that opposite the towing-path 6 feet.

When the country is flat, the ground is excavated to the depth of 2 feet 9 inches, which affords sufficient soil to elevate the banks for a depth of 4 feet of water, and when the ground is not perfectly level, 3 feet cutting is usually allowed.

The walls of the locks, culverts, and aqueducts are now usually built of stone.

As the canals belong to the different states, the boats are the property of individuals, who pay a moderate sum per mile for them, and each passenger conveyed by them. They are about 80 feet in length, 15 in breadth, and weigh about 20 tons, and usually draw about a foot of water, when the passengers are on board. They have about forty yards of tow line, and are drawn by three horses, at the rate of a little more than 4 miles an hour.

Supply of water. Many of the towns in the United States are supplied by means of

wheels; at Richmond, water is raised from the James River to a height of 160 feet by two wheels, 18 feet in diameter, and 10 feet in breadth, with a fall of 10 feet. There are two force pumps, with barrels of 9 inches in diameter, and stroke about 6 feet in length; one wheel can throw upwards of 65,000 cube feet in 24 hours into the two reservoirs, each of which is nearly 200 feet in length, 100 in breadth, and 10 feet in depth.

The iron main that connects the pumps with the reservoirs is 8 inches in diameter, and 2400 feet in length.

The Fairmount water-works, commenced in 1819, for the supply of the city of Philadelphia, are the largest and finest of their kind in America. They are situated on the east bank of the Schuylkill, two miles north-west from the city, and contain an area of thirty acres, the greater portion of which is occupied by an oval-shaped mound, 100 feet in height, with the sides variously inclined according to the nature of the formation; on its summit, at an elevation of 100 feet above mid-tide of the river, and about 50 feet above the highest ground in the city, are four reservoirs, which contain together 22,000,000 gallons, one of which is divided into three sections and serves as a filter. The reservoirs have a gravel walk around them, and are arrived at by several inclined planes.

A dam is erected across the Schuylkill, 1600 feet in length, 150 feet wide at the base, and 12 feet at top, its height varying from 12 to 36 feet. It is formed of earth and stone; the length of its overfall is 1204 feet, the eastern embankment 270 feet, and the head arches through which the water flows into the mill-race 104 feet. At the western end of the dam is a short canal, with two guard and two lift locks, for the use of the navigation company.

In January, 1839, the water rose 10 feet 2 inches above the top of the dam, but did not seriously injure it.

The mill-race is a parallelogram, excavated through a compact mass of gneiss rock, 419 feet in length, and 38 feet in depth; its width is 90 feet, and its depth is 6 feet below the overfall of the dam. A paved avenue, 253 feet in length, and 26 feet in width, bounds it on one side, and on the other rocky cliffs 80 feet in height; at the north end are head arches, which permit the passage of a body of water, 60 feet in width and 6 feet in depth, into the race. There is a waste gate to draw off the water, whenever it is required, and discharge it below the dam.

The buildings which contain the machinery are constructed of stone; and are in length 238 feet, and in width 56 feet. The lower floor is divided into 12 parts, 4 of which contain the double forcing-pumps. The others are occupied as fore bays, which lead to the water-wheels.

The water-wheels, five of which have been put in motion, are 15 feet in diameter, and 15 feet in width, and formed of wood with iron shafts, each of which weighs 5 tons; the wheels work under 1 foot head and 7 feet fall, and each forces 1,250,000 gallons of water into the receiving basin in the space of 24 hours, with the stroke of the pump of 4½ feet, the diameter of which is 16 inches, the wheel making 11½ revolutions in a minute. When the wheels make 13 revolutions, which they occasionally do, 1,500,000 gallons are pumped up.

The water-wheels are sunk below the ordinary line of high water; this does not, however, produce much effect, until there is a depth of 16 inches on the wheel.

The pumps are worked by a crank on the water-wheel, which is connected with the piston at the end of the slide. They are fed under a natural head of water from the fore bays of the water-wheel, and are calculated for a 6-feet stroke, but they are generally worked with not more than five. They are on the construction of the double-forcing, and are each connected with an iron main 16 inches in diameter, which is carried along the bottom of the race, to the foot of the mount, and thence up the bank into the reservoir, 92 feet in height.

The lowest estimate of the quantity afforded by the river in dry seasons is 440,000,000 gallons in twenty-four hours, and the average quantity of water raised by each wheel and pump is 530,000 gallons daily; but when the whole six wheels are put in motion, 6,000,000 gallons can be thrown up in twenty-four hours; and it is calculated that the average daily consumption is not more than two-thirds of that quantity.

The reservoirs are lined with stone, and paved with brick, underneath which is a bed of strong tenacious clay, and a thick lining of lime cement, made water-tight; they are in depth 12 feet. The water is conducted into the city from the centre reservoir by two iron mains, one 20 inches and the other 22 inches in diameter; each is nearly 10,000 feet in length. In the year 1821, iron distributing pipes were substituted for those of wood, which had been laid down only three years previously, for a distance of thirty miles; up to January, 1840, there were 109 miles of iron main, the greater part of which was obtained from England.

There are upwards of a thousand fire-plugs throughout the city; the cost to each family per annum for its supply of water is five dollars; the hotels and public buildings pay in proportion to their consumption.

Cincinnati water-works are on the Ohio; horse-power was originally used, but there are now two steam-engines, one of which works a double force pump, 10 inches in diameter, with a four-feet stroke, and throws up into the reservoirs 1000 gallons per minute; the other works a pump 20 inches in diameter, with an eight-feet stroke, and throws up 1200 gallons per minute.

From the reservoirs, which are built in stone, and cemented, the water is conducted by iron mains, 8 or 9 inches in diameter, into the basin, where it is distributed by leaden pipes.

Pittsburg receives its water from the Ohio, by a steam-engine of eighty-four horse power, which, by means of its pumps, throws a million and a half of gallons into a reservoir, 116 feet above the level of the river, from whence it is distributed by iron mains 15 inches in diameter, into the town.

Albany, on the Hudson, and Troy on the same river, obtain the purest water from the high ground in the neighbourhood; reservoirs are formed at a sufficient elevation, and of the requisite capacity, from whence it flows through iron mains to the different quarters of the town.

Boston originally derived its supply from wells, and according to a report furnished to the state, there were 2767 for public use, 33 of which were Artesian.

Montreal, and many other towns, are now supplied with water by means of steam power, which, no doubt, will become universal; and when all the works contemplated at New York are completed, the town, which is now inadequately served, will be wonderfully benefited.

The Croton aqueduct, upwards of 40 miles in length, is a subterranean brick tunnel, ascending at the rate of nearly 14 inches per mile from New York to Croton; after the trench was cut, and the aqueduct built, the earth was backed over the aqueduct, to a depth of 4 feet on the crown, where it was levelled down to a width of 8 or 10 feet, the sides being sloped with a talus of one and a half to one. Wherever a valley is crossed, a solid wall 15 feet in width at top, with sides battering one-twelfth to one, is built with stone, on the top of which a bed of concrete is laid, and on it is constructed the covered aqueduct, which is at bottom 6 feet wide, at top 7 feet, and 8 feet in height; the side walls being of stone, in courses, 39 inches thick at bottom, and 27 inches at top.

Across the river at Croton is thrown a dam; and 500 or 600 acres of water form the great reservoir, which for every foot in depth is calculated to contain 100,000,000 gallons of water. The dam is 100 feet in length, 70 feet wide at bottom, 7 feet at top, and the average height is 40 feet; it is built of stone and hydraulic cement.

The water passes from the reservoir by the corporation tunnel, 180 feet in length, and a mile further it crosses Lounsberry brook, by a culvert 6 feet in diameter and 66 feet in length; where it crosses the valley, the grade line is 40 feet above the brook, and 55 to the top of the aqueduct.

Five miles beyond, the Indian brook is crossed by a culvert 8 feet in diameter, and 142 feet in length, and the aqueduct is conducted through Benvenue tunnel, 720 feet in length, and the Ackers brook tunnel, 166 feet in length. At half a mile from Indian Brook is Hoagshill tunnel, 276 feet in length; from thence to Sing Sing are several valleys; it then passes through a tunnel 336 feet in length, cut in the solid rock. Soon after a chasm 70 feet deep, worn by the Indian brook, is crossed by an aqueduct bridge of 88 feet span, with an elliptical arch rising 25 feet, resting on stone abutments; the aqueduct is lined with cast-iron plates. A mile further are the two state prison farm tunnels, one 416 feet, the other 375 feet in length; and half a mile further Hollis Brook tunnel is entered; here, in crossing the valley, the grade line is 35 feet above the stream, and the top filling of the aqueduct 49 feet. The culvert is 131 feet in length, and 6 feet in diameter. A mile beyond is Ryders Brook, where the foundation wall is 20 feet high from the bed of the stream, and 34 feet to the top line of the aqueduct. The culvert is 100 feet in length, and 6 feet in diameter; a viaduct then crosses the road, built of stone, with an arch 20 feet span. The Austin Farm Tunnel, 186 feet in length, being passed, there occur several valleys, and when it arrives at Mill River, the grade is about 72 feet above the surface of the water, and the aqueduct is 87 feet in height. The culvert is 25 feet in diameter, and in length 172 feet. After quitting Mill River, the aqueduct passes through five culverts, and two miles below is the White Plains Tunnel, which is 246 feet in length. At Jewells Brook the aqueduct crosses by an embankment 62 feet in height, where there is a culvert 148 feet in length, and 6 feet in diameter, and another for the road 141 feet in length, and 14 feet in width. At Wiltseys Brook, 18½ miles from the Croton dam, the aqueduct crosses, and the culvert is 137 feet in length, and 6 feet in diameter, and at Dobbs Ferry Tunnel it passes entirely through earth for a length of 262 feet. At Storms Brook is a culvert 137 feet in length and 6 feet in diameter; as it proceeds from Dykemans Brook, the top of the embankment is 35 feet above the surface of the country.

The tunnel at the Saw Mill river is through earth and rock for a distance of 684 feet;

the foundations are afterwards 42 feet above the valley. The culverts here are 90 feet in length and 25 feet in diameter, and are double.

At Nodines Run, the aqueduct passes at a considerable elevation by a tunnel in the solid rock, 810 feet in length; the line then crosses the valley of Tibbetts Brook, where the culvert is 107 feet in length, and 6 feet in diameter.

At Harlem River, where the aqueduct is to cross, there is a depth of water of 26 feet at ordinary high tides, and its width is about 610 feet; here it is intended to build a bridge 1420 feet in length, 18 feet in width, between the parapet walls, and 27 feet from out to out. There are to be sixteen piers of stone, six of which will be in the river, and ten on land. The river piers are to be 40 feet by 20 feet, and to have a height of 84 feet, to the springing of the arches diminishing as they rise. The arches are to span 80 feet, whilst those on land will span only 50 feet. In the centre the arches are projected to be 100 feet above the level of high water; the height to the top of the parapet walls will consequently be 116 feet, and the total height about 138 feet; when finished, it is intended to carry the water over in iron mains, 2 or 3 feet in diameter.

At the Manhattan Valley iron pipes or inverted siphons are to be used, as the valley is upwards of 100 feet below the grade line of the aqueduct.

Twenty-six miles of the works were completed in April, 1840. Ventilators are to be placed at every mile distant, and the water on its arrival at New York is to be received into a reservoir 35 acres in area, the northern half of which is to have a depth of 20 feet, and the southern portion 25 feet; and it was estimated that the quantity of water would be about 160,000,000 gallons. Pipes or mains, 30 inches in diameter, are then to convey the water to another reservoir on Murray Hill, of five acres, and capable of containing 20,000,000 gallons, the difference of level of which and that of the pool at Croton being 46 feet, which allows a fall of about 14 inches per mile.

According to the engineer's report, the whole work, with the exception of the bridge over Harlem Strait, would be completed in 1842; it was proposed, after the cofferdams were constructed, to lay down pipes which would supply the water, whilst this, the most difficult part of the operation was in hand.

Various impediments have occurred during the progress of this gigantic undertaking, which have prolonged it beyond the time specified; it is, however, nearly terminated: its cost is estimated at two millions sterling.

Railroads. — The internal improvements that have taken place in America during the last thirty years, particularly in the extension of railroads, is truly astonishing; the states of the Union have endeavoured to rival each other in contributing lines to form one great national means of communication; it seems intended that railroads should spread throughout the whole of this vast continent like the meshes of a net, and embrace every spot occupied by its inhabitants. The progress already made is sufficient to indicate what will be done in a few years: when the great works now in hand are completed, commerce will derive such increased advantages, that we may hope, not only that the bond of union between the states will be thoroughly cemented, but that the whole people will be brought more closely together, and become as it were one family with a common interest.

The railroads, first projected for the purpose of connecting certain towns and districts, were designed without regard to any general plan; the lines being undertaken by companies independent of each other, various and often conflicting regulations were adopted; and much evil has arisen from this want of unanimity in the several operations. Whenever chartered companies have united and appointed a board of directors to carry out a plan suited to their common interests, the most beneficial results have been produced.

The first great chain of railroad commences at Portsmouth, in New Hampshire, and has almost an uninterrupted course to Pensacola, in Florida. Another line from the same place extends to Boston, Providence, and Stonington, in Connecticut, where it crosses Long Island Sound to Greenport, and then continues to Brooklyn, near New York; after crossing the river Hudson, it proceeds to Jersey, New Brunswick, Trenton, Philadelphia, Baltimore, Wilmington, and Washington. From thence to Fredericksburg, Richmond, Petersburg, Gaston, in North Carolina, Raleigh, Columbia, Branchville, and Augusta, in Georgia, then to West Point, Montgomery, and Pensacola, in Florida. Of this extensive line of communication nearly the whole is complete, and in the year 1840 upwards of 1600 miles were travelled over.

From Boston commences another grand chain, which passes Worcester, West Stockbridge, Albany, Schenectady, Utica, Syracuse, Auburn, Rochester, Attica, and Buffalo. The length of this line is about 530 miles.

From New York lines are in progress which, when finished, will extend upwards of 500 miles.

From Philadelphia is a line to Sunbury, Williamsport, and Erie, on the lake of that name, a distance of 420 miles.

By means of railroads and canals a distance of 400 miles is accomplished, from Philadelphia to Columbia, Hollidaysburg, Johnstown, and Pittsburg.

From Baltimore to Wheeling, 280 miles, the canal and railroad extend throughout; and the same kind of communication exists from Richmond, in Virginia, to Covington and the Ohio river. From Charlestown to Louisville, Cincinnati, and the Ohio, the line, when complete, will be upwards of 700 miles.

The great Atlantic line is considered the main trunk to which all others seem united; the western states are carrying out lines of railroads and canals of not less than 2000 miles in length.

The first lines laid down were with iron rails and chairs, on stone blocks, which were frequently so split by the frost, that it was necessary to remove them; the rails also became deranged, and extremely dangerous for the passage of carriages. Numerous methods have been adopted in the states to remedy the inconvenience arising from the great changes of temperature, as will be seen in this brief account of their railroads. The usual breadth between the rails is 4 feet 8½ inches, and when two lines are laid down, the distance maintained between them is usually 6 feet.

In the southern states, where a line is carried over low and marshy ground, and a difficulty is found in obtaining earth to construct the embankments, a series of timber trusses are substituted, which often rise 10 or 12 feet above the level of the plain; on these the longitudinal timbers are laid to carry the rails. Piles of from 14 to 16 inches in diameter, not sharpened, are first driven in, forming two lines the width of the way; when these are perpendicular, inclined struts are placed on the outside, which passing at the upper end under the transverse timbers, and abutting at the lower upon another short pile, render the woodwork tolerably secure.

Another method is to drive four slanting piles, two one way and two the other, each pair uniting at top under the longitudinal timbers, and in the middle of the width at bottom, where transverse binding pieces are firmly bolted to them, and secured either by additional piles or cross sleepers. Occasionally a double series of St. Andrew's crosses are used, but they have generally been found subject to considerable movement when in connection with the locomotive engine.

The cost of the American railroads is considerably less than in England: many of the single tracks have not exceeded 4000*l.* a mile, and, including buildings and all requisite apparatus, the average expense does not seem to exceed 20,000*l.* per mile.

One system frequently adopted seems extremely economical sills of white oak 7 feet 10 inches long, and about 9 inches in depth, are laid across the road, at a distance of 5 feet from centre to centre; and notches are cut at the ends, into which are laid longitudinal pieces of heart of pine wood, 9 inches in depth, 5 inches in width, and 4 feet 7 inches apart. On their inner edge, plates of rolled iron 2 inches wide, and half an inch thick, are spiked down with wrought iron spikes, 5 inches in length; and where the plates form a junction, there is an additional plate of sheet iron one-twelfth of an inch in thickness; this system is found to answer when the locomotive engines are from fifteen to twenty horse power, and the cost per mile in America does not exceed 600*l.* The locomotive engines, when their boilers are filled, seldom weigh more than 15 tons, and their driving wheels are placed in the fore part near the fire-box; they are 5 feet in diameter; the front of the engine running on four wheels, half the diameter of the large ones.

On the truck which runs on the fore wheels are a number of friction rollers, placed in a circle, in the centre of which is a vertical pivot, working in a socket of the frame-work which supports the engine. The friction rollers support the cylinder and part of the boiler, and the truck of the carriage acting on the pivot describes a portion of a circle, which is of great service when the engine is not running on a level road; at each side of the engine a guard is usually attached to prevent it being thrown off the rail; this is nothing more than a strong piece of timber, fixed to the front axle, and supported by two wheels, of 2 feet in diameter, which run on the rails a few feet in advance. This piece of timber is on the outside, shod with iron, slightly bent upwards, which clears away any obstruction that may be offered to its progress.

The Boston and Lowell railroad is in length about 26½ miles; it has eighteen viaducts, one of which is 1600 feet in length, and fifty-one bridges. The maximum rise is 1 in 528, or 10 feet per mile, and the least radius of curvature is 3000 feet.

Where the line approaches Lowell, the cutting for 1000 feet is through the solid rock, which at the top is 60 feet in width, at the bottom 40 feet, and the mean height the same. At the commencement fish-bellied edge rails, weighing thirty-five pounds per yard, on cast-iron chairs, were laid down. The chairs were fitted on stone blocks, which rested on stone cross sills; the bearings were about 3 feet from centre to centre, and the blocks and sills were carried throughout by a longitudinal wall constructed of rubble, laid dry, 3 feet in height, 2 feet 6 inches wide at the footing, and 2 feet at the top. The space between these walls was packed in with clay, and other earth that could be easily obtained.

The construction not being found to answer, the foundations have since been laid in with sand and gravel; a trench being opened for its reception, 3 feet in depth, and 7 feet in width, it was well rolled and rammed; sills of stone, 6 feet in length, and 12 by 6 feet

were then laid down; and the H rail in 15 feet lengths was adopted; the weight of which was fifty-five pounds per yard.

The Boston and Worcester line is in length forty-four miles, and has several deep cuttings and high embankments; where it crosses the Charles river is a viaduct of masonry and trestle work. The rail used is that of the T form, weighing about 38½ pounds to the yard. The bars are about 15 feet in length, carried by iron chairs, weighing about 15 pounds each; they are tightened by means of two wrought iron keys.

The chairs are placed on sleepers of cedars 5 inches square, and in lengths of 7 feet; these are laid crossways at regular distances of 3 feet from centre to centre, and bedded on piers of rubble masonry; this was, however, found insecure, and a longitudinal under sill of chestnut 8 inches by 3 inches has been added throughout.

The Western railroad, extending from Worcester to the valley of the Hudson, is in length more than 116 miles; and the four summits are from 900 to 1500 feet above the level of the sea. The width of the track is 4 feet 8½ inches; the rails are of a parallel form, 3½ inches in depth, 4 inches on the base, and 2 inches at the top; the weight is fifty-five pounds per yard. They are laid upon sleepers of chestnut, 7 feet in length, 7 inches in depth, and 12 inches wide. These sleepers rest upon others of hemlock wood, laid longitudinally, 8 inches in width, and 3 inches thick, so placed, that they measure 4 feet 10 inches from centre to centre; where the joints of the iron rails occurs, there are four cross-timbers, 3 feet in length.

The rails are kept in their place in the usual manner, and the chairs are spiked into the sleepers.

The maximum inclination is 60 feet in a mile, and the minimum radius of curvature 1146 feet.

The Boston and Providence line is in length 41 miles, and the least radius is 5730 feet; the highest inclination is 25 per mile in the direction towards Boston, and on the other side 37 feet 6 inches; the highest elevation is 256 feet above the level of the sea.

The Granite Viaduct at Canton is 700 feet in length, and where it crosses the Neponset river is 60 feet in height. The wooden bridges on this line are 1200 feet in extent, and their spans vary from 30 to 125 feet.

The rails are of the H pattern, in lengths of 15 feet, weighing 55 pounds per yard. The iron chairs weigh ten pounds each, and are only used where the rails join each other; they are let into the sleepers, and secured by four spikes. The rail is fastened by broad spikes, four on each sleeper; 6 inches in length, half an inch square, and weighing nine ounces each. There are cross ties of white cedar under the rails, laid 3 feet from centre to centre.

Providence and Stonington railroad is 47 miles in length, has rails of the H pattern, in lengths of 15 feet, weighing fifty-eight pounds per yard, with square ends. The cast-iron chairs weigh ten pounds each, and are spiked down to the sleepers, with spikes nine ounces each. The sleepers of white cedar are laid 3 feet apart, are 7 feet in length, and 6 inches in thickness; they rest on sills of hemlock, 8 inches by 3 inches, and where the joints occur, there are additional piers 5 feet in length laid under them.

The highest elevation is 302 feet above the level of high water, and the maximum rise not more than 33 feet in a mile; the minimum radius of curvature 1637 feet.

Norwich and Worcester railroad is in length 58½ miles; its maximum grade is 20 feet per mile, and the average inclination is 11 feet per mile.

Long Island Railroad is in a state of progress, and one portion of the line rises 200 feet in a mile. The other gradients do not exceed 40 feet in a mile, and the minimum radius of curvature is 5280 feet. The rails are of the T pattern, weighing thirty-eight pounds per yard, resting on cast-iron chairs; these are confined on stone blocks, placed on cross ties of timber. The sleepers are of red cedar, in lengths of 8 feet, and 6 inches square. The iron chairs weigh fifteen pounds each when they are placed on the sleepers, and twenty pounds each on the stone blocks. An iron tie crosses the road, and holds the opposite stone blocks together; it is a bar of half an inch thick, 2¾ inches in width, and 4 feet 8½ inches in length.

The top part of the rail rests on the chair, and is secured by a double key.

Harlem Railroad, twenty-six miles in length, is a double track, and is travelled for three-fourths of its length by steam power.

The tunnel through which the line passes is cut through a solid rock, composed of quartz and hornblende, of so compact a nature that masonry was unnecessary. It extends 844 feet, and is in width 24 feet, and 21 feet in height. On this road the plate rail is laid down; it is 2¼ inches in width, and five-eighths thick; it is secured to longitudinal timbers 77 feet long, laid across ties of locust and cedar, placed 3 feet 6 inches apart.

New York and Albany Railroad at one point attains an elevation of 770 feet, but the gradients seldom exceed 30 feet per mile. The length of this line is 147¾ miles, and the radii of curvature is seldom above 1500 feet.

Camden and Amboy Railroad, in length sixty-one miles; the radii of its curves are

about 1800 feet, and the usual gradients 20 feet per mile. The rails are the H pattern, in lengths of 16 feet, weighing forty-one pounds per square yard. The rails are supported on stone blocks, 18 inches square, and 12 inches in depth, placed in a continued trench, at regular distances. Where the rails join, there are cast-iron plates spiked down below them, which, by means of a notch cut in the rail, prevent its moving endways; the rails are attached to each other at the ends by an iron plate 4 inches in length, which is riveted to each rail; the rivet has a play to allow of contraction and expansion.

On the top of the stone blocks is a piece of wood 2 inches in thickness, to adjust the placing of the rail.

Wherever the clay occurred, it was taken out, being so readily affected by frost, sand and gravel being substituted.

New Jersey Railroad, thirty-four miles in length, has its least radius of curvature 2000 feet, and the steepest gradient 26 feet per mile. The rails are of the T form, and weigh thirty-seven pounds per yard; they are in lengths of 18 feet, with square ends. The rail rests upon its two upper flanches on chairs, a single key keeping it in its place. The chairs weigh fifteen pounds each, and are placed at equal distances, measuring 3 feet from centre to centre; they are secured to cross sleepers of cedar wood and chestnut.

There are two timber viaducts, one over the Possaic, the other over the Hackensack, which are worthy of notice.

At Bergen Hill is a deep cutting, a mile in length, and at one part 50 feet in depth, 35 feet of which is through hard rock; more than 500,000 cubic yards were excavated.

The Viaduct at Raritan is on the plan called after Colonel Long; its length is 1700 feet, and its spans vary from 112 feet to 145 feet; the depth of the truss being 22 feet, and the width between the rails at the top 31 feet. There are seven piers and two abutments, faced with granite, and filled in with blue and red shale stone; this viaduct has two stories in height; the lower floor is supported by trusses, and a double roadway is carried by means of joists laid 4 feet apart. The chairs that confine the rails rest on strong pieces, 11 inches in width and 4 inches thick, pinned down to the floor at top, which serves as a roof. The braces of the truss-framing abut upon thin plates of sheet iron.

Parts of the floors draw up, to allow the passage of vessels at certain appointed times.

Columbia and Philadelphia railroad is 81½ miles in length; the maximum gradient is 30 feet per mile, and the minimum radius of curvature 631 feet. The deepest cuttings are between 30 and 40 feet, and the highest embankment is 80 feet.

There are 75 stone culverts, varying in span from 4 to 25 feet, 20 viaducts, the piers and abutments of which are stone, the structures above of timber, and 33 bridges.

The Schuylkill viaduct is of timber, formed into distinct trusses, the whole width, from out to out, being nearly 50 feet, which is sufficient to allow three separate ways, two of 18 feet 6 inches, and the other of 4 feet for foot passengers. There are six piers and seven spans; the whole length of the viaduct is 1045 feet; the height of the floor above the water-line is 38 feet.

Valley Creek viaduct has four equal spans of 130 feet clear, and the stone piers vary in height from 56 to 59 feet. The woodwork consists of a lattice bridge, with the railway carried over the top.

East Brandywine viaduct has four spans, two of 88 feet 6 inches, and two of 121 feet 6 inches. The clear width is 18 feet 6 inches, and the whole length of the platform 477 feet, the clear height above the water 30 feet.

The West Brandywine viaduct has a platform 835 feet in length, which is 72 feet above the water; the line is carried over the top of the framing.

Big Conestoga viaduct is in length 1412 feet, the platform is 60 feet above the water. The greatest span is 120 feet, and the lattice timber-work is upon Town's plan.

Little Conestoga viaduct has also stone piers and abutments, the length of the platform is 804 feet, and its elevation above the water 47 feet.

Mill Creek viaduct is 540 feet in length, and is 40 feet high.

Pequea viaduct is a single span of 130 feet, it is in timber, on the plan of Mr. Burr.

The length of the single track is 163 miles, six miles of which have granite sills, on which are flat iron bars; 16 miles with wooden string pieces, plated in a similar way with iron; two miles with stone blocks, and sills with edge rails; and 137 miles, with stone block and edge rail, with timber sills across the track.

The granite track has trenches cut in the line of its direction about 22 inches in depth, into which is compactly placed layers of broken stone. Granite sills are then laid, varying in length from 3 to 12 feet, and 12 inches square; into these holes are drilled five-eighths of an inch in diameter, and 3½ inches in depth, into which plugs of locust wood were securely driven. The iron bars, 15 feet in length, 2¼ inches wide, and five-eighths of an inch thick, are spiked to these wooden plugs. As horse-power is used, there is a pathway of broken stone and gravel 6 inches in depth.

The timber track. — Trenches were dug across the road 4 feet apart, 8 feet in length, 12 inches wide, and 16 inches in depth; broken stone was thrown into them and well rammed,

then sills of chestnut and white oak were laid down, in lengths of 7 feet 6 inches, and 7 inches square, notched, to receive a yellow pine string piece, 6 inches square, which is spiked down securely. On this are the flat iron bars, and the horse-way is formed as before described.

Edge Rails on Stone Blocks and Sills.—Trenches were dug in the direction of the length of the road, 28 inches wide, and 24 in depth; at every 15 feet these were connected by a cross-trench, 16 inches in width: broken stones were rammed into them, and blocks and sills were settled by the means of heavy rammers. The granite blocks are 20 inches long, 16 wide, and 12 deep. The sills, also, of stone, 6 feet 6 inches long, and 12 inches square, are sunk in the trench at every 15 feet. The rails have a bearing on the blocks at every 3 feet. The chairs, which are of cast-iron, weigh 15 pounds, and are secured to the sills and blocks by bolts driven into cedar plugs inserted in the stone. Each chair has two bolts, weighing 10 ounces each, and between the chair and stone block is a piece of tarred felt. The rails are of rolled iron, 15 feet in length, parallel top and bottom; their depth is 3½ inches, and their weight, per yard, 41¼ pounds. The rail is fastened to the chair by two wrought-iron wedges, each weighing 10 ounces. The horse-path is similar to the others.

Edge Rails on Stone Blocks and Locust Sills.—The locust sills are 15 feet apart on the straight lines, and 9 feet on the curves, and the remainder of the work is the same as the edge-rail track already described.

There are turn-outs for the horses at certain intervals. On this line of railroad all the bars used belong either to individuals or to companies, whilst the motive power is found by the state.

The locomotives run daily about 77 miles.

There is an inclined plane at the Philadelphia end 2714 feet in length, and rising 185 feet. Another at Columbia is 1914 feet in length, and rises 90 feet. The cars are moved up and down by a stationary engine of 60 horse-power, and an endless rope 9 inches in circumference, which passes round horizontal grooved wheels, placed at the top and bottom of the planes.

Allegany Portage Railroad, its length is a little more than 36½ miles, and its total rise and fall 2570 feet, of which 2007 feet are overcome by planes, the inclination of which varies from 4° to 5½°, or from 7¼ feet to 10¼ feet, for every 100 feet base. They are all straight, both on plan and section. The total length of their base is a little more than 4¼ miles; the rest of the gradients are about 15 feet per mile. All the embankments are 25 feet in width; at the top there are four viaducts of considerable extent: that over Connemaugh is a single arch of 80 feet span, the top of the stone work is 70 feet above the surface of the water; there are 68 culverts, 85 drains, several bridges, 10 inclined planes, 11 levels, and one tunnel, 901 feet in length, 20 feet wide, and 19 feet in height to the soffite of the arch.

The edge rails are parallel, and made of rolled iron, weighing 40 pounds per yard; they are supported by cast-iron chairs, weighing 13 pounds each, and the rail is secured in them by an iron wedge. The stone blocks under them contain each about 3 feet 6 inches of cube stone, and are placed on a bed of broken stone, at a distance of 3 feet from centre to centre. At the head of each inclined plane are two stationary engines of 35 horse-power each, which work an endless rope, and can draw up four cars loaded with 7000 pounds weight, and let down four at the same time; from six to ten changes can be made in an hour. A safety car is in attendance in case of any accident occurring to the rope.

In the formation of this railroad there were

337,220	cube yards of common excavation.	
212,034	- -	slate or detached rock.
566,932	- -	hard pan or indurated clay.
210,724	- -	solid rock.
14,857	- -	solid rock in the tunnel.
967,060	- -	embankments carried over 100 feet.
67,327	perches	slope wall.
13,342	- -	vert and wall in drains.

Philadelphia and Reading Railroad is 59 miles in length, and in one instance the gradient is 19 feet to the mile; the others vary from 18 inches to 11 feet in the same distance, there are three tunnels on the line.

The H rail is used; the weight is 45 pounds 2 ounces per yard; the lengths are 18 feet 9 inches, with square ends. About eight of these lengths weigh a ton; the sleepers upon which they are secured are of white oak, laid transversely about 7 feet in length; they are brought to a face on the under as well as upper side, in order that a true bearing might be obtained throughout; they are 7 inches in depth, and laid at a distance of 3 feet 1½ inches from centre to centre. Under them is a foundation of broken stone, in a trench excavated to the depth of 14 inches, and in width 12 inches; the length was 2 feet more than that of the sleepers bedded on them. After these walls were laid, and the timbers placed, the spaces between them were filled up level with clay, or any other material at hand. The

rails are let in about ¼ of an inch throughout, except at the joinings of the rails, where the chairs occur. The chairs are 6 inches square at the base, and ⅝ of an inch in thickness, and the rails are bolted down to them securely, the hole in the rail being made a little larger than the bolt, to allow for expansion. The bolt and nut weigh 7 ounces, and the chair 10½ pounds; the latter is held by four spikes, 6 inches in length, the heads of which passed over the edge of the chair.

In a mile of road there were 71 tons of rail, 5910 pounds of chairs, 4524 pounds of spikes, and 481 pounds of bolts and nuts.

About 30 miles from Philadelphia is a tunnel, the length of which is 1932 feet, the width 19 feet, and the internal height 17 feet. The sides are cut quite perpendicular, as high as 10 feet 9 inches, and above this the section is a half oval, rising 6 feet 8 inches; there is no lining of masonry except at the ends, the rock it passes through being the Grauwacke slate, and sufficiently strong without it.

Beyond the northern end of the tunnel, the Schuylkill is crossed by a stone bridge, 18 feet 4 inches wide; there are four spans, each 72 feet, and 3 piers of 8 feet; the roadway is 24 feet above the level of the river. The versed sine of the arches is 16 feet 6 inches; the arch is the segment of a circle whose radius is 47 feet 6 inches. Below the water the foundations are carried down to 10 or 12 feet in depth; Roman cement was used instead of mortar, and the whole of the superstructure is executed with cut stone.

Baltimore and Ohio Railroad extends 80½ miles, the road bed is in width 26 feet; 41 miles from Baltimore there is an inclined plane, in length 2150 feet, rising 80; this is followed by another, 3000 feet in length, and 100 feet rise; the summit is 813 feet above mid tide, and is called Parr's Spring Ridge. From thence the line descends by an inclined plane, 3200 feet in length, and 160 feet in height, and by another 1900 feet in length, and 81 feet in height, after which the gradients vary from 37 to 52 feet per mile.

The viaducts are all of stone excepting two; between Baltimore and the Potomac there are thirty-three.

The rails are sometimes laid on granite sills, and at others on timber sleepers; the iron rails are in 15 feet lengths, each pierced with eleven oblong holes, to receive iron pins.

Baltimore and Port Deposite Road is 95 miles in length, its maximum inclination is 20 feet per mile, and its minimum radius of curvature 2000 feet.

Under each line of rails is a sill sawed out of white pine, 8 inches by 6 inches, in lengths of from 12 to 40 feet. These are laid flat in longitudinal trenches; on these, at distances of 3 feet from centre to centre are cross timbers of white oak and chestnut, 8 feet in length and about 8 inches by 6; each has four notches, two on the lower side, 8 inches wide, and two on the upper, 7½ inches, in which is a wedge for the purpose of making fast the longitudinal piece; the thickness left between the upper and lower notch is always 2½ inches. The lower notches embrace the under sills, and are made to fit, so that no lateral movement can take place.

The rails are nearly rectangular on their section, and weigh 40 pounds per yard; they are 2½ inches wide at bottom, 2¼ at top, and 1¾ inch in height; their length varies from 17 feet 9 inches to 18 feet 3 inches, and their ends are cut obliquely to an angle of about 60°. Each is vertically perforated by five holes, by means of which they are secured to the longitudinal timbers; the ends of the rails are lodged on plates of rolled iron, ¼ inch in thickness, and about 5¾ by 4¼ inches. On the upper side of these plates are two small ledges, extending their whole length parallel to each other, through which the rail passes, and is prevented from having any lateral movement. Two 9-inch bolts keep the plates secure.

Baltimore and Susquehanna railroad is in length 56 miles; its summit level is 1000 feet above that of high water; its steepest ascent is 84 feet per mile, and descent 59 feet. The least radius of curvature is 950 feet.

Lexington and Ohio railroad is 92¾ miles in length, the minimum radius of curvature is 1000 feet, and its maximum inclination 30 feet per mile. Where it descends the valley of the Green River is an inclined plane 4000 feet in length, and 240 feet in height.

To these may be added the Portland, Saco and Portsmouth in the department of Maine, in length 50 miles; Concord, in the same department, 35 miles; in Massachussetts, the Boston and Maine, 17 miles; Berkshire, 21 miles; Felchburg, 50 miles; Naschua and Lowell, 14 miles; Northampton and Springfield; Old Colony, and some others. In new York is the Attica and Buffalo, in length 31 miles; Auburn and Rochester, 78 miles; Auburn and Syracuse, 26 miles; Buffalo and Magara, 22 miles; Erie, 53 miles; Long Island, 96 miles; Utica and Schenectady 78 miles; Reading, 94 miles; South Carolina and Columbia, 202 miles, and a great many others in progress; those already completed amount to nearly 2700 miles in length.

CHAP. VIII.

CIVIL ENGINEERING IN BRITAIN.

Among the great nations of antiquity and of modern Europe, we find the engineer trusted and employed by the governments, and when great works were undertaken, their cost provided for out of the public funds. The peculiar nature of our constitution has caused a contrary course to be pursued; the increase of commerce in Britain, and its augmentation of capital, have directed the attention of individuals not only to the improvement of machinery, but to the best method of conveying their manufactured goods to the port from whence they are to be transmitted to foreign lands. Hence arose the necessity of improving the roads and bridges, forming canals, convenient harbours, lighthouses, &c., and latterly, spreading over the whole face of the country a network of railway communication.

To commercial enterprise, and not to the government, is due whatever improvements have been made in the science of engineering: private study, and not an Institute, produced Brindley, Jessop, Rennie, Chapman, Huddart, Watt, Priestley, Smeaton, and others, who, in the last century, gave a character to the science, and permanently established it as a profession. Mechanical knowledge formed the groundwork of their acquirements, and the increasing wants of the commercial world called them into active operation; the necessity of an undertaking was no sooner made known than intellect and energy contrived to execute it. The prosperity of Britain is based upon her industry, and the success which has attended the speculations of manufacturers has induced the formation of companies for the establishment of canals, docks, harbours, and other public works.

As it is our boast that the management of public improvements is entrusted to those who pay for them, the government interferes no further than is necessary for the protection of private property: when a project is decided on, plans are forwarded to some public place of meeting in the county or counties interested in it, and notices are transmitted to the inhabitants of the towns and villages, as well as to each individual whose property is in the slightest degree interfered with. The names of the owners and occupiers of the soil are registered, with their assent to or dissent from the measure; this document is forwarded to the office of the justices of the peace of each county, previous to applying to parliament. The London Gazette and the country journals then announce the proposition, and make it as public as possible. A petition drawn up and presented to the houses of parliament is sent with a draught bill, prepared by the engineers and solicitors of the company, which is duly considered by a committee of the legislative houses, and if no important objections are taken, the measure is assented to; when the whole of the subscribers are summoned to appoint a managing committee, treasurer, engineer, and assistants, to carry out the work.

Plans and specifications are then advertised of the several portions of the undertaking, and contractors offer tenders for its performance, the lowest being generally selected; the contractor is bound to give the work his personal attendance, to submit to the superintendence of an inspector, appointed by the committee of management, and to the works being measured every month, when an order is given for the amount to be paid; he is also required to furnish securities for the completion by a certain time; when this is effected, the management devolves upon a committee appointed by the great body of shareholders.

The engineer thus becomes instrumental in advancing the welfare of the nation; without him none of these improvements could be carried on, and hence the absolute necessity for acquiring all the various branches of knowledge connected with the undertakings alluded to.

Science and art are too often considered to have no reference to each other, and hence the principles of construction have been fostered by the Institute of Civil Engineers, whilst what relates to taste and fancy has been considered the province of the Royal Academy.

The future historian of Britain will not refer to her architectural remains, but to the vast works of the engineer, by which to judge of the habits and civilisation of the age. The architect is too generally confined to the pencil, in other words, to the production of a beautiful drawing, a point by no means to be undervalued; but of what use is the creation of designs, when unaccompanied by a knowledge of the construction by which they can be carried into effect? A picture will not show whether the material has been well selected or judiciously employed, or if the voids and supports are properly proportioned: on the other hand the study of the engineer is often too exclusively directed to the display of mere mechanical skill, without the attempt to produce a good effect; still the demand for the ability in question is now so great, that without an increased energy on the part of

the architect, he will be superseded by the engineer; there is no reason why the labour of necessity or usefulness should not be embellished by taste, and a great nation has a right to expect the union of science and art, based on the severest integrity, in those to whom millions are entrusted for her improvement.

It is not possible to form an estimate of the sums expended by individuals and companies during the last century on roads, bridges, canals, harbours, docks, and mining operations, where the services of the engineer were demanded; that the amount exceeds that of the national debt there can be no doubt, and a thousand million sterling would not be overrating the total outlay. Many of the bridges have cost upwards of a million, and the railways completed considerably more than a hundred million; how much of this vast sum has been improvidently expended cannot now be estimated, but probably more than half. We may consider that to the middle of the last century, the drainage of the land, the embankment of rivers, and the extracting of ores, was performed by individuals who had no claims to the title of civil engineers; it was his knowledge in mechanics that induced a member of the Royal Society to select Smeaton as the builder for Eddystone Lighthouse. In the middle ages towns and cities were walled in, and castles and cathedrals built, by the enterprising confraternities of Masons, who travelled from place to place under the direction of a governing body: to them were confided constructions of every kind, and the intelligent head of the Lodge acted as architect and engineer; old London Bridge, and the walls which surrounded Dover, Hartlepool, and other harbours, evince their skill in such constructions. The same causes which led to their dissolution buried for a time the knowledge which had rendered such important service to the country; but when internal tranquillity was restored, the whole extent of our coast, and the navigable rivers which discharge themselves into the ocean, received improvement, though this was often effected by men who had obtained a reputation abroad; vast tracts of land were redeemed from a state of marsh by engineers from Holland: all these important undertakings were conducted in a rude and imperfect manner; the philosopher had not directed his studies to what was useful, and mathematical knowledge was slighted by the unlearned practitioner.

The Ports and Harbours of Britain first claim our attention, and although it is not possible to do more than briefly describe them, we may, where information is afforded, give an account of some of the improvements they have undergone; it must, however, be admitted that much remains to be performed, before they will answer the growing wants of our great commercial intercourse.

The Thames, that gentle, deep, majestic king of floods, seems to have been the resort of commerce at a very early period, and on its banks, where the capital is now situated, formerly stood Llyn-Din, or the town on the lake. This river, which is of such importance to British commerce, passes through a rich and fertile district; the basin of the Thames, or the land it drains, has been computed as equal to an eleventh part of England and Scotland, and as containing nearly a fifth of the entire population. It rises on the Coteswold hills, and receives its supplies at first from the Lech, the Colne, the Churne, and the Isis; the latter flows by Cricklade, and is rendered navigable for small craft at Lechdale, on the confines of Gloucestershire and Berkshire. The Windrush and Evanlode run into it a little below, and at a short distance further the Thame enters it near Dorchester; the whole is then called Thame Isis. After passing Reading, it receives the Kennet, and below Staines the Wey; when flowing through the metropolis, it has other tributaries in the Lea, the Ravensbourne, the Darent, and the Medway.

From Lechdale to London Bridge, the distance by the river is 146½ miles, with a total rise from low water mark, at the bridge, of 248 feet; the tide flows up 18¾ miles, to Teddington, where is the first lock to aid the navigation. The low water surface of the river falls about 16 feet 9 inches from Teddington lock to London Bridge, or 10¾ inches per mile on an average. The high water mark at Teddington is 18 inches above the high water mark at London Bridge, and the time of high water is later by about two hours. The fall of the bed of the river in this distance is about 12 inches in a mile.

The Thames flows with a regular and steady current, and is of a considerable depth above Greenwich; at ebb tide it is generally from 12 to 13 feet; the tides at London Bridge rise ordinarily about 17 feet, and at extreme springs as much as 22 feet. Ships of almost any tonnage can get up to Deptford; those of 1400 or 1500 tons to Blackwall, whilst St. Katherine's Docks will not receive vessels of above 800 tons.

The whole course of this noble river measures upwards of 200 miles, and it drains a surface of country equal to about 5000 square miles; its meandering is considerable, as a straight line drawn from its two extremities is not much more than half the before-mentioned distance. Its velocity varies from ½ mile to 2¾ miles per hour, and the mean has been computed at about 2 miles per hour.

On the southern banks, below London Bridge, are many docks, and the government establishments of Deptford, Greenwich, and Woolwich, and on the Medway, Chatham and Sheerness. On the northern banks are several docks, belonging to the St. Katherine,

London, and East and West India Companies, and many private establishments for ship-building.

St. Katherine's Docks. A company was incorporated by an act passed 6 Geo. 4. c. 105, and the docks were opened the 25th of October, 1828. The capital raised by shares amounted to 1,352,800*l.* and an additional sum of 800,000*l.* was borrowed on the security of the works which had been performed; the engineering department was under the direction of Mr. Thomas Telford, and the warehouses under that of Mr. Philip Hardwick.

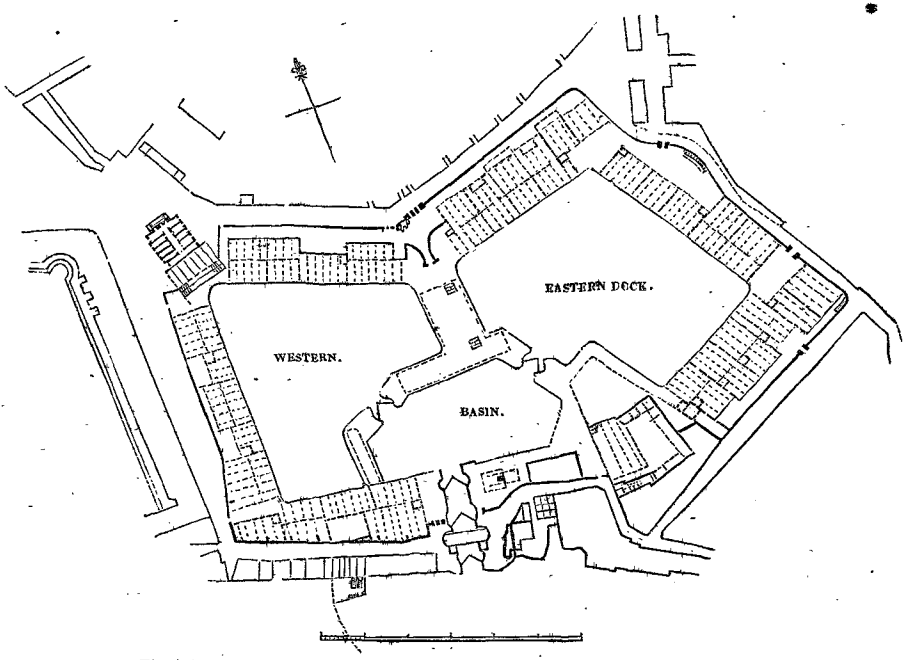


Fig. 308. ST. CATHERINE.

These docks occupy a space between Tower Hill and East Smithfield, and communicate with the river by a lock 180 feet in length, and 45 feet in width; its construction admits vessels of 600 tons burthen, 3 hours before the time of high water. The depth of water on the sills at spring tides is 28 feet, at dead neaps 24 feet, at low spring tides 10 feet, and at low water neap tides 12 feet, Trinity datum.

The area occupied by these docks within the walls is 24 acres, 11 of which are water; the two docks communicate with each other by a basin, and are surrounded by wide quays and lofty brick warehouses, where the goods are at once housed by cranes out of the holds of the vessels.

Between the docks and the Tower is a wharf, having a frontage towards the river of 187 feet.

Before these docks were commenced, numerous borings were made to the depth of 40 feet.

The lock entrance, and the sills under the two middle lock gates, are fixed at a depth of 10 feet under the level of low water mark of an ordinary spring tide. The vessels pass from this lock into an entrance basin of about two acres, and thence, through a single pair of gates, 45 feet in width, into the eastern dock, and by similar means into the western, each of which contains nearly two acres.

The bottom of the docks and basin is 4 feet above the outer and middle lock sills, and the height of the quays is 8 feet above the water in the docks, which is always preserved at the same level by means of two steam engines of 80 horse power each, which can fill the lock in seven minutes, and the process of lockage may, without affecting the water in the basin, be continued, as long as there is sufficient depth of water outside the lock gate.

The small area of these docks, and there being but one entrance, suggested the employment of steam engine pumps, as well as the laying the lock sill so much under the level of

low water on the shore; by which means a greater number of vessels can be admitted every high water.

The two steam engines can be separately worked, but are connected by a line of triple cranks, which move six double-action pumps. The pumps are 3 feet in diameter, and have a stroke of 4 feet 6 inches; these are united to a horizontal iron pipe, 3 feet 6 inches in diameter, bent at one end, where it descends into a well, 8 feet in diameter, the bottom of which is 3 feet below low water mark. Communicating with this well is a culvert, 8 feet wide, 6 feet 6 inches high, and 170 feet in length, formed, as is the well, of ashlar masonry; the bottom is laid 2 feet below low water, at spring tides; over the outer end is placed a grating, to prevent any matter from entering and entangling the pump valves. The water raised by the pumps can be discharged either into the entrance lock or the basin.

At spring tides the depth of water on the sills of the outward lock gates is, at the first hour after flood, 16 feet; at the second hour, 21 feet 2 inches; at the third, 24 feet; at the fourth, 26 feet 6 inches; and at the fifth hour after flood, and at high water, 28 feet.

At the first hour after high water it is 24 feet 6 inches; at the second, 20 feet 10 inches; at the third, 18 feet 2 inches; at the fourth, 15 feet 7 inches; at the fifth, 13 feet 2 inches; at the sixth, 11 feet 3 inches; and at low water, 10 feet.

During neap tides, the depth of water at the first hour after flood is 13 feet 6 inches; at the second, 16 feet 10 inches; at the third, 20 feet 3 inches; at the fourth, 22 feet 7 inches; and at the fifth hour, and at high water, 24 feet.

And at the first hour after high water, 21 feet 11 inches; after the second 18 feet; the third 16 feet 2 inches; the fourth 15 feet 6 inches; the fifth, 14 feet; the sixth, 12 feet 10 inches; and at low water, 12 feet.

The entrance lock is built of grey stock bricks, laid in mortar made with lias lime; the platforms, hollow quoins, bond stones, and copings of the lock walls, are of Bramley Fall

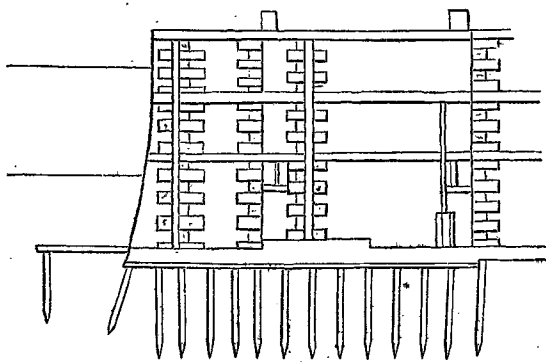


Fig. 309. SIDE OF ENTRANCE LOCK.

stone, and the whole so cemented that they form a solid mass. As the site of the docks and quays is upon a hard stratum of gravel, it was found necessary to line the bottom of the docks, and puddle the back of the walls, as well as to place the counterforts upon foundations impervious to water.

An artificial concrete, composed of blue lias lime mixed with eight parts of coarse sand, was kneaded into a thick mortar, and spread over a bed, a foot in thickness, of sufficient size to receive the breadth of the wall of the counterforts and puddle. A wooden sill was laid under the front edge of the wall, and a row of sheeting piles, 14 feet in length, and 9 inches in thickness, was driven along the side of it, their joints for 3 feet downwards being closely caulked.

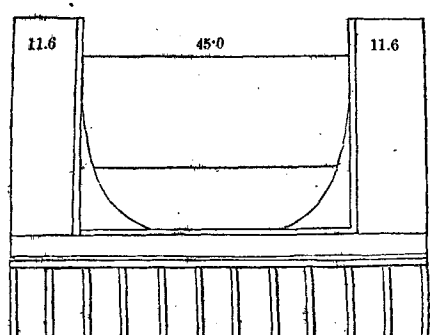


Fig. 310. SECTION OF ENTRANCE LOCK.

The facing wall of the whole of

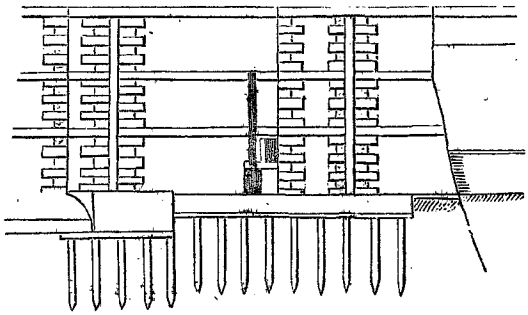


Fig. 311. PART OF SIDE OF LOCK.

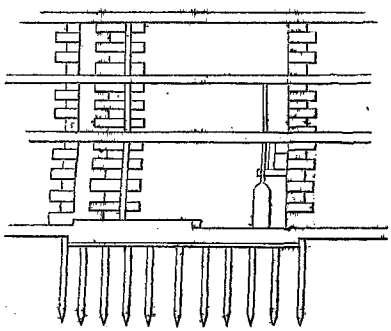


Fig. 312. LONGITUDINAL SECTION.

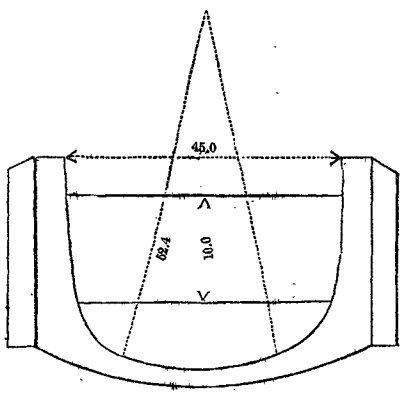


Fig. 313. SECTION IN MIDDLE.

the quay, to within 14 inches of the top, was laid in blue lias lime mortar, and the remainder worked with Dorking lime.

The brickwork was flushed, and every four courses varied in their diagonal direction.

Commercial Docks are situated on the opposite side of the river to the West India Docks, and nearly opposite their upper entrance. There are six docks, the largest of

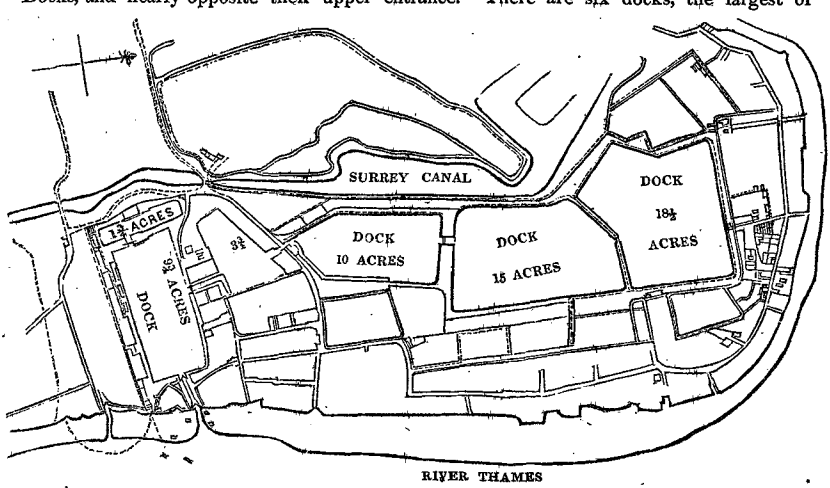


Fig. 314. COMMERCIAL DOCKS.

which, the Greenland, covers 9¾ acres. The next dock westward, 1¾ acres, No. 3, 3¾; No. 4, 10 acres; No. 5, 15 acres; No. 6, 18½ acres. The space comprised altogether by these spacious docks is 70 acres, of which 58 are water.

London Docks were established by a company of merchants, under the authority of an Act of Parliament, obtained in June, 1800. The act had for its outline, that the holders should have 5 per cent. interest annually, guaranteed upon the capital they advanced, and the dividends were never to exceed 10 per cent. The capital of the company at first was to be 1,200,000*l.*, with the power of adding another 300,000*l.*, and the interest of all loans destined to complete this capital was to be paid before the other dividends. The proprietors of from 500*l.* to 10,000*l.* or more had votes in respective proportions, but no one was to have more than four.

Nine proprietors were sufficient to call a general meeting, independent of the half-yearly meetings, for the examination of the current accounts.

The basis upon which the purchase of lands or property necessary for the docks, quays, and warehouses was distinctly established, and the company was empowered to erect a wall of inclosure, and to supply the basins from the Thames; to construct all necessary bridges, and to lay down water pipes and form sewers, subject to the superintendence of the commissioners of sewers. The company engaged to complete the works in seven years, to preserve a certain depth of water before the entrance of the docks, but was forbidden to build any vessels.

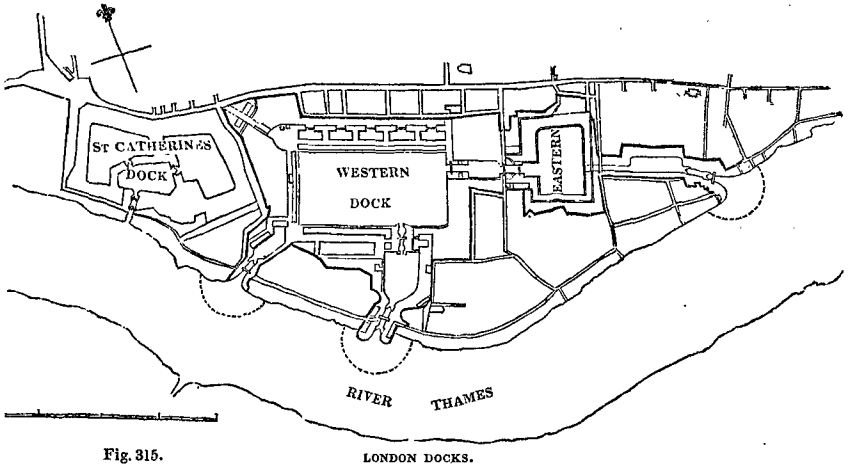


Fig. 315. LONDON DOCKS.

The dock rates were fixed at per ton, according to the official guaging of the vessels, as follows: — For every ship, trading between London and the ports of Great Britain, 1*s.*; Ireland, parts of France, Flanders, Germany, and Denmark, 1*s.* 3*d.*; to the Baltic, 1*s.* 6*d.*, and to other places in proportion, whilst the highest duties were to eastern Asia and the East Indies, 2*s.* 6*d.* per ton.

The merchandise shipped or unshipped within the docks pays the same duty as in the port of London, for anchorage, moorage, and housing.

All vessels laden with more than twenty pipes of wine or brandy are obliged to enter the London Docks; and there are numerous other clauses referrible to the nomination of officers of management, &c.

The lower communication from the river is by a long cut, which is called the Wapping entrance, and higher up the river is another called the Hermitage.

Along the sides of the docks, and near the edges of the quays, are erected ranges of sheds, of a very simple construction: behind these sheds, which first receive the cargoes from the ships, and in a parallel direction with them, is a line of warehouses, four stories high, containing beneath them spacious arched vaults: and covering an area of 120,000 square yards. In front of these splendid masses of building, and along the whole length of the sheds, are iron railways, with others at right angles, which lead from the quays to the several loop-hole entrances of the warehouses.

These works were commenced in 1800, under the superintendence of Mr. Rennie, and in five years the establishment was opened for merchant vessels; during the progress, a steam-engine of twenty horse-power was constantly at work, to pump out the water which filtered into the excavations. This engine, made by Boulton and Watt, raised nine

cubic yards of water per minute to the height of 33 feet, and consumed two bushels of coals per hour; it turned a drum bearing an endless chain, which glided in an horizontal direction upon rollers, and passed over a second circular drum; to which was attached an eccentric pin, the action of which raised the piston of a powerful pump.

In order to prevent the links of the chain from becoming loose by their expansion, and to make them always press equally upon the two drums, so that they should transmit and receive motion from each other, there were two parallel upright posts, between which the chain passed; here was introduced a heavy roller, which mounted or descended in grooves and rested on the upper part of the chain, thus, by its constant weight, exerting an equal tension on the two drums.

There are two capacious docks; the western covers an area of 20 acres, being 420 yards long, and 320 yards wide. The eastern dock has an area of about 7 acres. The entire area within the boundary walls of the whole is a little more than 71 acres.

The tobacco warehouses, on the north side of the tobacco dock, which is more than an acre in extent, are the largest and most convenient to be met with. They cover 5 acres of ground, and will contain 24,000 hogsheads of tobacco.

The vaults under the warehouses include an area of 18 acres, and can admit 6000 pipes of wine.

East India Docks were erected after the passing of the act in July, 1803, which authorised the formation of a company consisting of thirteen directors, elected in fourths every

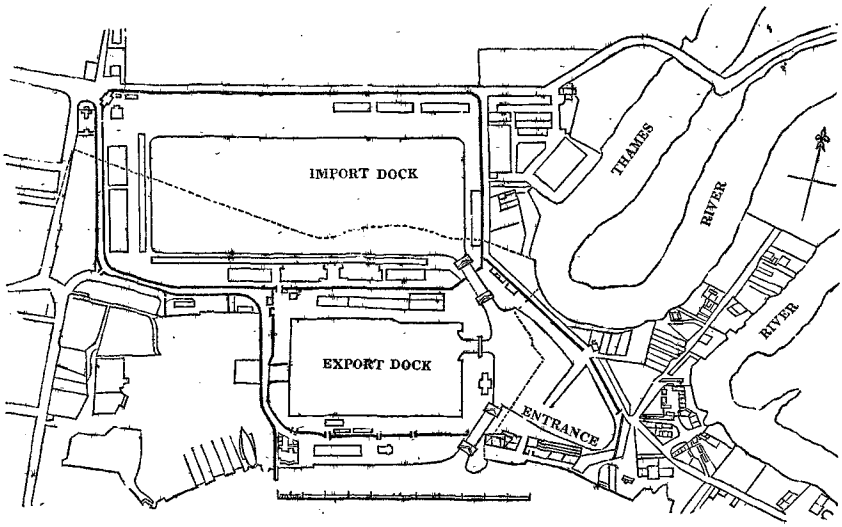


Fig. 316. EAST INDIA DOCKS.

year. Every fourth year four nominations are made instead of three: each director to possess at least twenty shares, and four to be directors of the East India Company. The general interests and accounts of the company are laid before two meetings, held in January and July every year. Persons who do not possess five shares are not allowed to vote.

The import dock contains 19 acres, the export nearly 10 acres, and the basin 3 acres; the two docks are connected with the basin by two short locks, making a total superficies of 32 acres. The depth of these docks, measured from the levels of the quays, is 27 feet.

Vessels enter from the Thames by a lock opening in the west side of the basin, over which is a light iron bridge, 4 feet in breadth, for foot passengers.

The import dock is 1410 feet in length, and 560 feet in breadth. The export dock is 760 feet in length, and 463 feet in breadth.

The various works were executed under the direction of Mr. Ralph Walker and Mr. John Rennie.

Fronting the river is a quay nearly 700 feet in length, and the export dock has a lofty building in which is machinery to mast or unmast the largest vessels.

Since the dissolution of the East India Company as a commercial corporation, these docks have been opened to vessels from all parts of the globe.

Brunswick Wharf, in front of the East India Docks. In 1834 this quay was found to be in a state of decay, and being required for the accommodation of a large class of steam vessels, Messrs. Walker and Burgess were employed as engineers to put it into a proper state, and the new iron piling and wharfing were executed.

A trench 6 feet wide was opened in the direction of the intended line, and the guide piles were then driven; the main piles, which are of iron, were placed at intervals of 7 feet, and the intermediate bays were filled in with the iron plates. The piles are each in two pieces, the upper one fitting into a socket-head formed on the lower, the union being made perfect by a strong screw bolt: each sheet pile is secured at the top by two bolts to the uppermost wale of the woodwork immediately behind them; they are of iron $1\frac{1}{4}$ inches in thickness, and the weight of each is 17 cwt.

These plates filling up the spaces over the sheet piling are bolted to the main piles, and to each other, and the joints stopped with iron cement, and where the mooring rings are introduced, they are cast concave with a hole to allow a bolt to pass through, which is secured as well as the land ties from the main piles to the old wharf, which was not disturbed.

The West India Docks are considerably larger than the London, and are situated about $1\frac{1}{2}$ miles below them in the Isle of Dogs, on a peninsula formed by the winding of the Thames. These docks were commenced on the 12th of July, 1800, and as early as the

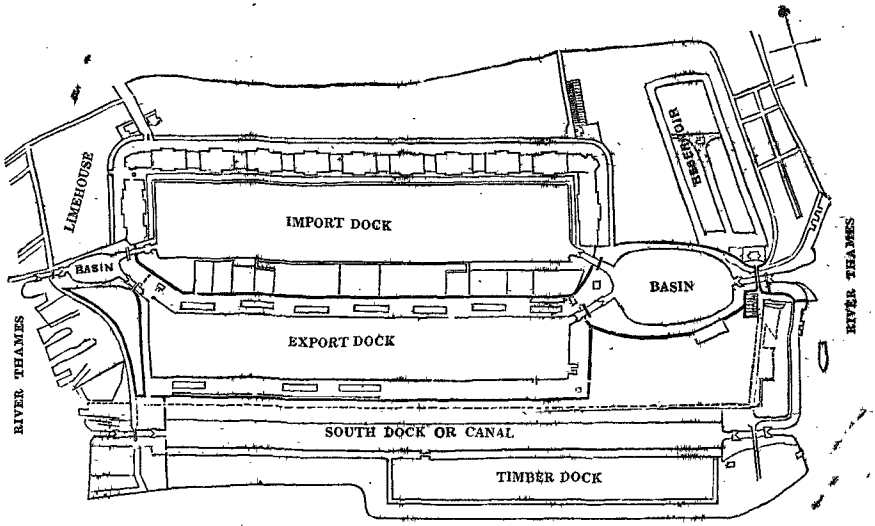


Fig. 317. WEST INDIA DOCKS.

month of September, 1802, vessels entered the import dock. There are two docks, each about 890 yards in length, running parallel to each other; the largest, 500 feet in breadth, and destined for vessels returning from the West Indies, contains about 30 acres; the other, 400 feet broad, about 25 acres. The docks, basins, and locks, together form an area of 68 acres, whilst the total superficies, including the quays and warehouses, is 140 acres. 204 vessels can be admitted into the import, and 195 into the export dock, forming a total of 120,000 tons.

At the upper end is the Limehouse basin, containing 2 acres, and at the lower the Blackwall basin, containing 6 acres.

The docks lie almost from west to east, and the principal entrance, that of the import dock, is from the west; at the upper and lower end is a basin with three locks; the first communicates with the Thames, the water being retained by double gates; the second and third locks also have double gates, and communicate with the export and import docks. By these arrangements vessels can enter the basin whatever may be the state of the tide, and remain as long as may be required.

As the water in the docks is very little higher than that in the basin, there is no stress upon the lock gates, and remaining some time in the basin before it is passed into the docks the sediment is entirely deposited.

Parallel with the northern quay of the import dock is a range of sheds, 880 yards in length, which communicate with the warehouses, six stories high. The sheds are supported by cast-

iron columns, and paved with slabs of granite, except at the water's edge, where there are iron plates for the more easily working of the trucks, which are drawn by two men, who transport the various casks to the entrance of the large warehouses.

Along the southern quay is a shed with an iron roof covered with slate, and also supported by iron columns; this shed is 443 yards in length. To counteract the effects of expansion and contraction, of which the metal is susceptible, the iron tie-beams which rest on the columns are not closely united, but a sufficient interval is allowed to admit of some play.

Under the sheds are spacious cellars, with octagonal pillars of stone, supporting flat brick arches; they are lighted by vertical openings taken from the interior of the sheds above them. Where two vaults intersect, a cylindrical well is built up, through which the light descends from a lantern. On a level with the floor of the sheds, plates of cast-iron cover these wells, and in them are fixed five lens or glass illuminators. Reflectors have also been most ingeniously introduced to distribute light in various parts.

Iron railways are not used on the quays, but in their stead large slabs nicely fitted together, upon which the friction of the wheels is inconsiderable. In the middle of the pavement there are two rows, running parallel with the quays and warehouses, and opposite to each crane a double row conducts to the warehouse doors, or the sloping passage to the vault.

East of the docks is the mahogany shed, which is remarkable for the machine used in piling up the vast logs imported from the West Indies; five men, by the aid of this machine, move logs weighing as many tons with facility.

William Jessop furnished the plans for the West India docks, and superintended their execution, as did Mr. Gwilt those for the warehouses.

Deptford is situated on the southern bank of the Thames, not far from the mouth of the little river Ravensbourne, which rises at Keston, in Kent, near the remains of the Roman camp.

Henry VIII. established there a royal dock, or king's yard, which has been considerably improved since that time; at present it comprises upwards of 31 acres, contains wet docks, slips for men-of-war, basin, mast ponds, and several storehouses. The old storehouse is a quadrangular pile, and was built in 1543. The roofing, which covers some of the slips, is a fine example of carpentry. At a short distance on the north is the victualling yard, with steam mills for grinding corn, ovens for baking biscuits, cattle-sheds, slaughter-houses, a cooperage, and packing-rooms. There are houses for the residence of all the officers belonging to this most important establishment.

Woolwich, on the same bank, farther down the river, has a much more extensive dockyard, which was established at a very early period. The ship Harry Grace de Dieu, of 1000 tons, was built here in 1512. The dockyard has been enlarged from time to time; at present it is about 5 furlongs in length and 1 in breadth. Within this area are dry docks, mast ponds, slips, smithery, anchor manufactory, model lofts, storehouses of various descriptions, mast houses, sheds for timber, and dwellings for the superior officers. Several of the largest vessels in the British navy have been built there.

The dry dock, erected under the superintendence of Mr. Walker, is one of the most commodious lately built. After the site was excavated, a foot of brickwork was laid over the whole, then a course of granite 3 feet 6 inches in thickness. The base is 230 feet in length, and of a proportional breadth; the dock will contain vessels of 300 feet in length, owing to the excellent manner in which it is arranged.

Another dock, similarly constructed, 360 feet at the base, will admit vessels of 400 feet in length on the upper deck.

Many timber piers have been carried out from the banks of the Thames within the last few years, for the convenience of the steamboat passengers, some of which are between 300 and 400 feet in length; the most important of these are at Erith, Greenhithe, and Grays; it is difficult to say how long the timbers may remain uninjured by the Teredo navalis, which does great injury below Gravesend.

Gravesend, which contains a population of nearly 20,000 persons, being much resorted to during the summer months, has grown into considerable importance: steamboats are constantly arriving and departing. In 1833 an act was obtained to construct a new landing-pier, and thirteen months afterwards the present town pier was opened to the public; W. T. Clark, Esq. was the engineer employed by the corporation, and Mr. William Wood contracted to perform the work for 8700*l*. It extends 127 feet from the front of the town quay, and is 140 feet wide, being built upon cast-iron arches of that span, with a rise of 6 feet; the land arch springing from the stone wall of the quay, and all the others from columns. The transverse arches and framing, also of cast-iron, are supported by eight columns on foundations of Bramley fall-stone.

At the extremity of the platform is a T head 76 feet in length, and 30 feet wide, under which are contrived the steps which communicate with a floating vessel, which rises and falls with the tide, and is always level with the packets alongside.

The T head is supported upon cast-iron diagonal framing, 6 feet deep, on 18 columns, which are protected by transverse timbers, 13 inches square, bolted securely together. Under each of the columns are three cast-iron piles, 14 feet long and 15 inches in diameter; these were driven into the bed of the river until their tops were 15 inches under water, at low water ordinary spring tides. On the heads of each of the piles is an iron plate, upon which the column was placed.

The twenty-six columns of cast-iron which support the whole pier are each 18 feet high and 33 inches in diameter.

The platform of the pier is enclosed by an open parapet, and the ends of the T are formed into pavilions, which afford shelter in inclement weather. At the end of the pier is a cast-iron column 35 feet in height, including the base and lantern, which is lighted every evening with gas.

Particular attention was required to have the heads of the iron piles, which were driven into the chalky bed, perfectly level before the bases were put on, and this was effected by means of a wooden cylinder, 9 feet in diameter, and 9 feet in length, made of 3-inch deal battens, firmly keyed and hooped together, the lower end being shaped like a sheet pile, and shod with iron. This cylinder was lowered over each set of three piles, and loaded sufficiently to cause it to sink through the soft mud of the shore, when it was driven into the hard ground. The water was then pumped out, and the mud removed low enough to enable the workmen to reduce the heads of the piles to a uniform level by chipping, so that the bases of the columns were fitted down to the tops of the piles, metal and metal, and this operation was repeated as often as was required.

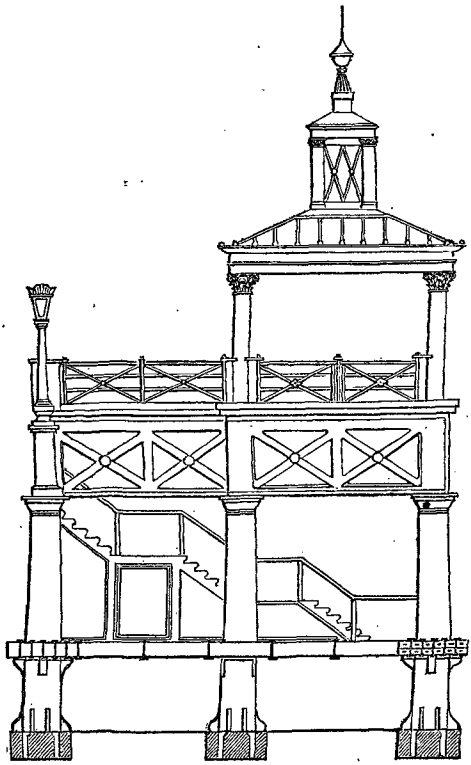


Fig. 318. TOWN PIER, GRAVESEND.

Upon the columns are placed cast-iron ribs, 40 feet in length; each arch is composed of two, secured together by 1½ inch screw bolts and nuts. The whole structure consists of four such arches, which are strutted by other castings, firmly screwed to them. The various portions of the iron framing, for the support of the platform, were fitted together in a temporary manner on shore, previously to their being applied to the columns, which prevented any cutting or chipping away of the iron work already placed.

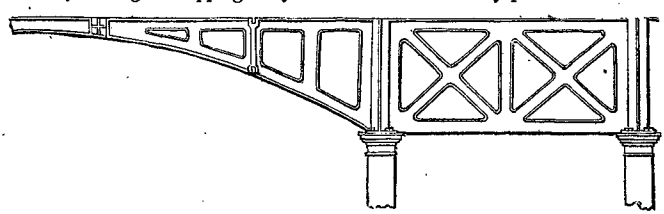


Fig. 319. TOWN PIER, GRAVESEND.

At the Terrace Gardens, lower down the river, another cast-iron pier has just been completed, under the direction of Mr. J. B. Redman, which projects into the river 200 feet at

high water. The total length, including the abutments, is 250 feet; it is terminated by a T head, 90 feet in length, and of the same width as the main portion of the pier, which is 30 feet. The platform is supported by 22 cast-iron columns, with girders of the same material.

There are three columns on each tier, with girders of 22 feet span, and three main spans to where the T head commences; the first two are each 50 feet, the other 51 feet. The columns are 28 feet in length, except in the first tier, which are shorter; their bases

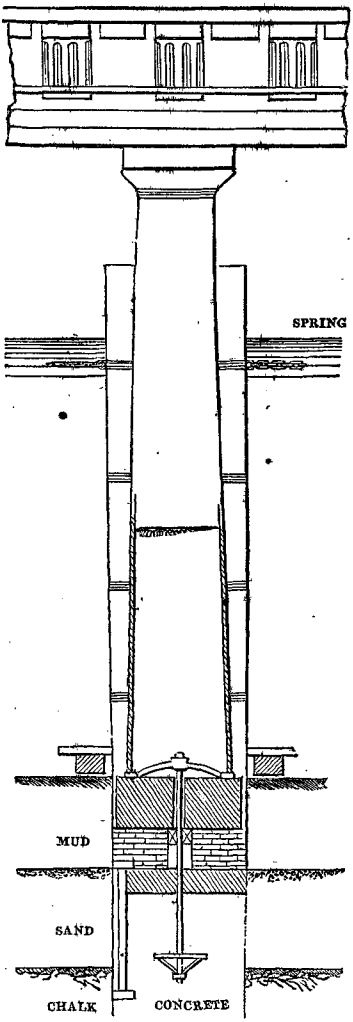


Fig. 320. TERRACE PIER.

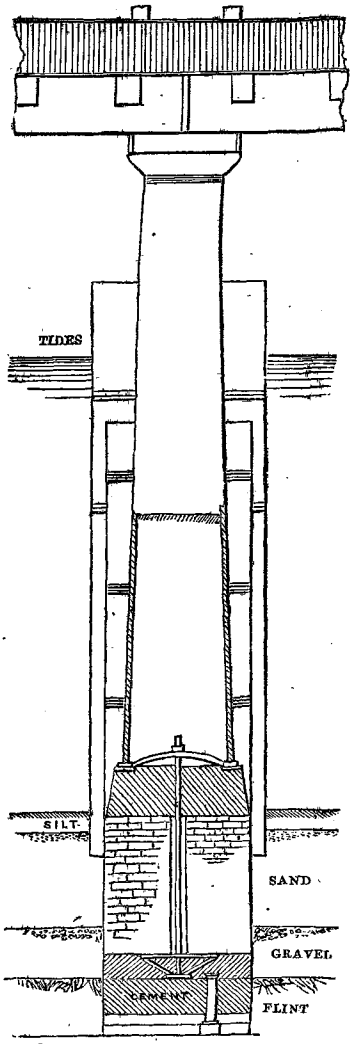


Fig. 321. TERRACE PIER.

are laid level with low water spring tides, and their caps 8 feet above the level of high water spring tides, which rise 20 feet, so that there is never less than 8 feet headway throughout.

By means of a tide guage, employed whilst the works were in progress, it was found that the greatest rise of the tide was 22 feet 9 inches, and the lowest ebb was 1 foot 9 inches

below the zero on the scale; which gave the total lift of the tide 24 feet 6 inches; but on October 18, 1841, the tide rose one foot higher.

The excavations for the several works are carried down one foot below the level of low water spring tides, and rest upon a bed of flints, which cap the chalk.

The first tier of columns, 15 feet long, is placed upon stone bases, which rest on brick piers 7 feet 6 inches square; and the other columns were fixed by means of cast-iron cylinders 6 feet in diameter, formed of segmental plates, firmly bolted together. When the first cylinder had been forced into the mud, others were placed upon them, and secured by iron bolts, thus forming a species of coffer-dam.

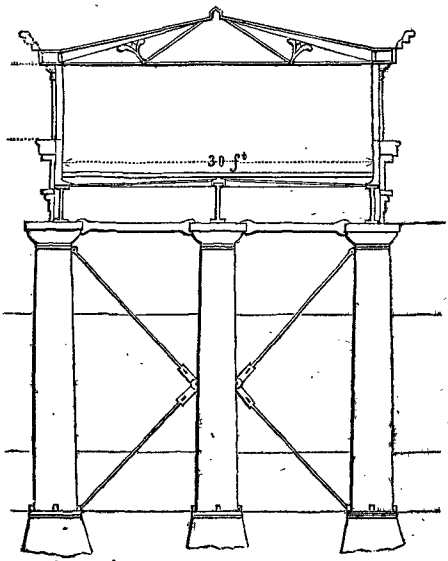


Fig. 322. TERRACE PIER SECTION.

To base some of the columns, it was found necessary to have cylinders 7 feet in diameter, supported with pieces of timber; when these cylinders were above high water mark, others, 6 feet in diameter, were made use of.

For the foundations of the T head, the outer cylinders or coffer-dams were not used, guides being substituted for them, formed by placing timbers on the land, bolted to the fender piles, and so placed as to enclose a tier of three cylinders; across these timbers planks were laid down and nailed, so that there was a square space through which the cylinders could sink; they were guided above at the level of high water by a ring of wrought iron, held by four guy chains secured to the fender piles; to the metal ring were attached four iron rollers, which enabled the cylinder to slide freely through it, by which means they were placed very correctly.

The cylinder plates are five-eighths of an inch in thickness, and when placed, they were weighted with five or ten tons of stone, according to the resistance presented.

After the several cylinders were sunk to their required depth upon the solid chalk, a floor was formed of two courses of dry brick, and a thickness of 18 or 24 inches of brickwork was brought up in Roman cement, with two courses of plain tiles, also in cement; this was done for the purpose of keeping out the spring water, which, in some of the foundations, was found to rise in considerable quantities; it was led up through a pipe 6 inches in diameter, bedded upon the dry courses below, to the mouth of which drains were formed, from where the water was most abundant. The water was pumped out by this means, and kept below the level of the work as it proceeded. When the bottom was found sound the pipe was filled with concrete, formed of Thames sand and Roman cement, and a blank flanch secured over the top.

After the cement foundation was completed, a cast-iron cross, with a wrought-iron holding down bolt through it, was bedded on the work; the rest of the brickwork was carried up in mortar, composed of blue lias and puzzolana in equal proportions, with two and a half measures of clean river sand, and iron hoops were laid between the several courses to bind the whole together.

The iron bolt was frequently plummed upright as the work proceeded, and a space of some inches was left around it to afford facility for its adjustment; after which it was filled up with concrete.

Upon this brickwork was laid a circular base of Bramley Fall stone, bored to pass over the bolt; and being properly bedded, the columns were lowered and placed upon it. Each is in one casting, 26 feet long, 4 feet in diameter at bottom, and 3 feet at top; one column, which rather exceeded 1½ inches in thickness, weighed 10 tons, the others averaged about 9½ tons each. They are held together at top by cast-iron cross-bracing frames, fitted and bolted between the caps. The three girders which rest on the first three columns, and those of the T head, are cast to one section; six of them are 54 feet 9 inches long, and the three, next the T head 55 feet 9 inches long.

The Doric entablature which surrounds the pier and forms the casing to the external girders and parapet is 7 feet in height, and rises 2 feet 9 inches above the platform.

The platform is of Memel timber; the joints are caulked down upon the girders, and are covered with 3-inch plank.

The front of the pier is protected by dolphins, one in the centre, and one outside each wing, and the whole of the piles are sheathed with copper. The dolphins keep the barge at a parallel distance from the T head, where the platform is approached by two flights of stairs, with landings at convenient levels between the outer rows of columns, and a transverse flight from above.

The roof of the pier is of iron; the principals are formed of two pieces of wrought angle iron, with a wood flitch between them, to which the slate boards are nailed; they are trussed with wrought-iron, with a cast-iron strut on either side. The supporting brackets are secured to the gutters by two wrought iron bolts, which are carried through the gutter. Six small skylights are placed over the platform at the entrance, to admit light when the shutters at the side are closed.

The lighthouse over the T head is supported upon four inclined truss bearers; the centre of the lantern is 40 feet above the datum level of high water; and the total height from the base of the outer foundations to the summit of the vane is 82 feet.

The pier, lighted by gas, was opened to the public two years after its commencement, in April, 1843. Messrs. Fox, Henderson, and Co. were the contractors.

Chatham has a dockyard and arsenal on the banks of the Medway, which were established about the reign of Queen Elizabeth; and Camden describes it as "stored for the finest fleet the sun ever beheld, and ready at a minute's warning." James I. formed the ordnance wharf, on the site of the old dock; since which time capacious wet docks, slips, mast houses, rope walks, sail lofts, smiths' shops, and other buildings, have been erected upon a very extensive scale, and some of the largest ships in the navy have been constructed there. Near the town of Rochester is a victualling office, composed of several extensive ranges of building, appropriated to the use of the shipping at Chatham, Sheerness, and the Nore.

Sheerness is another dockyard on the Medway, near where that river unites with the Thames; it is the chief town of the Isle of Sheppy, and situated at its extreme southern point. This yard was chiefly established for the repair of vessels that were but partially damaged; but during the last fifty years vast sums of money have been expended upon it to render the docks complete, and fitted for other uses.

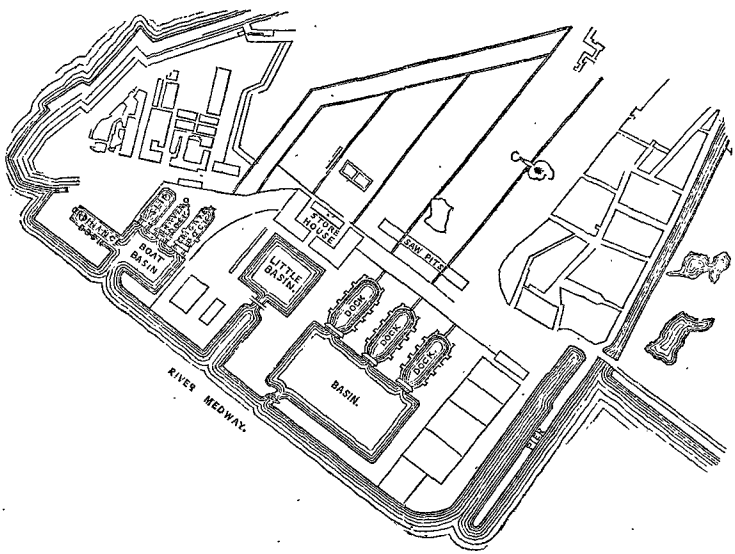


Fig. 323. SHEERNESS.

It is well supplied with spring water from a well sunk in 1781, 328 feet in depth. When the workmen had penetrated through the chalk, and were trying the strata with an auger, it suddenly dropped, and the water gushed up with such velocity, that the men could with difficulty be drawn out; in six hours the water rose 190 feet, and in a few days was within 8 feet of the top, and though constantly in use, it has never been lowered more than

200 feet; its quality is soft, and its temperature higher than that obtained from ordinary wells.

Docks and slips have been constructed upon the best principles, and a sea-wall, founded upon a solid bed, is built along the entire frontage.

After quitting the Thames, and continuing on the line of coast northward, we arrive at the river Crouch, which has left many deltas; one of these, called Foulness, advances considerably into the sea; the river itself is navigable for more than eleven miles.

Ten miles north of the Crouch lies Blackwater Bay, into which the Chelmar and other small streams empty themselves; some years ago the Chelmar was made navigable for small vessels to Chelmsford; the Colne carries small craft to Wivenhoe and Colchester, which are employed in the oyster trade.

One of the streams which pour forth their waters into this spacious bay is the Idumanum, on which Maldon is situated.

Fifteen miles farther north is another bay, into which fall the Stour and Orwell; both are of a considerable width at their mouth, and the first is navigable for 28 miles to Sudbury, where the Flemings established a manufactory for cloth in the fourteenth century.

Harwich, a populous sea-port and a market town, is situated at the north-east extremity of Essex, on a point of land bounded on the east by the sea, and on the north by the estuaries of the Stour and Orwell. The inhabitants are chiefly employed in ship-building, and vessels of considerable burthen have been launched from the convenient yards established here. The harbour is deep and spacious, and the anchorage good. More than 100 sail of the line and 400 colliers are reported to have been seen riding in safety at one time.

Numerous vessels are fitted out from this port engaged in the fishery trade, and there is a constant communication between it and the ports of Holland and Germany.

On the south side of Harwich the cliff which divides Orwell haven from the bay contains a stratum of a blue clay, about a foot in thickness, on which is another of the same thickness, of stone, containing numerous fossils.

Immediately opposite to Harwich, and at the south-east extremity of Suffolk, is a strong fortification, called Langard Fort; it is built upon a point of land united to Walton Colness, except at the time of high water, when it becomes an island, nearly a mile distant from the shore.

The Orwell is navigable to Ipswich, but the port is still much silted up, although in the reign of George III. an act of parliament was obtained to improve the course up to Stowmarket.

The Deben discharges itself at Felix Stow, north of Harwich Bay, and is navigable to Woodbridge, a distance of ten miles.

Orford, situated on the confluence of the Alde and Ore, was once a place of considerable importance: the keep of the ancient castle remains; its plan is polygonal, having 18 sides described within a circle whose radius is 27 feet; three square towers, placed around it at equal distances, flank the walls, each measuring about 22 feet in width, projecting 12 feet, and 90 feet high. The walls at the base are 20 feet in thickness; the whole is surrounded by ditches, and was formerly by a circular wall 40 or 50 feet in height; this Norman castle is chiefly built of Caen stone.

The decline of the town is ascribed to the loss of its harbour, occasioned by the bar thrown up, at the mouth, which has caused the sea to retire altogether. The accumulations of sand on this coast have also destroyed the importance that Aldborough once possessed, which is situated on the same river.

Southwold, on an eminence overlooking the German Ocean, is nearly surrounded on every side by the river Blith, which here discharges itself into the sea. The herring fishery once contributed to its wealth and importance. About the middle of the last century a pier was erected on the north side of the port, and a few years afterwards another on the south. Two docks were also laid down by the Free British fishery, and numerous magazines for depositing stores were constructed.

Southwold Bay, or Sole Bay, as it is commonly called, was rendered celebrated in 1672, by the action fought in it between the combined fleets of England and France against the Dutch, commanded by De Ruyter.

Lowestoft is situated on the easternmost part of the English coast, upon a lofty eminence commanding a fine view over the German Ocean; and near the edge of the cliff, north of the town, stands the upper lighthouse, erected in 1676, which is a circular tower of brick, 40 feet in height, and 20 in diameter. This lighthouse originally had its upper story or chamber glazed all round, and within was kept burning a coal fire, which was visible at night for a great distance at sea. In 1778 the brethren of the Trinity House altered this arrangement, and erected at the summit one of the newly contrived cylindrical lanterns.

Another lighthouse, of timber, is placed below, so that vessels coming into Lowestoft roads are directed to the Stanford Channel, which lies between the Holme and Barnard

sands. This channel is ¼ mile broad and ⅜ mile from the shore, and is continually changing its direction; it is, therefore, necessary constantly to move the position of this timber lighthouse, in order that it may be placed in such a manner that it covers the great lighthouse, to vessels entering. The herring fishery forms the principal trade, and the ships employed are about 40 tons burthen.

Yarmouth is admirably situated for the commerce of the north of Europe, and for the inland navigation of the county of Suffolk, from which it is separated by the Waveney. The town, which is in the county of Norfolk, is placed upon a bank of sand that became firm ground, and was first inhabited about the time of the Norman conquest, when a wall was built around the town, and a broad moat formed outside.

The haven has been a constant source of expense; the present is the seventh which has been formed, and it is yet subject to all the inconveniences of the former. It was executed under the direction of Joas Johnson, a Dutchman of some experience, who commenced his operations by driving and hedging down on the north side large stakes and piles to render the foundations firm; upon the south side the same system was adopted, that the refluent tide might be forced to run out by a north-east channel. Piers and a jetty were erected to prevent an overflow, and to preserve a sufficient depth of water for vessels to float at all times.

The north pier, which was the principal, was made 40 feet wide at bottom, 20 feet at top, and 235 yards long. The whole was executed with timber of large scantling braced together, and bound with iron. This pier was defended by a jetty, 265 yards long, 16 feet wide at the base, and 8 feet above. The south pier, 340 yards long, 30 feet broad, and 30 high, 24 feet of which were under water, was built to prevent the waters of the old haven from running out southward.

The haven measures between the two piers 1111 yards, and is constantly receiving some improvement. There are two lighthouses on the coast for the benefit of Yarmouth Roads, one at Caister and another at Garleston; this coast is very dangerous, and it is recorded that more than 200 sail of vessels and 1000 men perished in one night, in the year 1692.

Numerous sand-banks on this coast are continually shifting, but the sea has not encroached upon the shore since the sixteenth century. The great estuary, in the time of the Saxons, reached as far as Norwich, which was then situated on an arm of the sea. Since Yarmouth was first occupied, the sands have wonderfully increased, and a line of dunes is formed across the entrance of the entire estuary, which increasing both in breadth and height effectually has shut out the tides, and narrowed the passage of the river, which has varied its course several times; the tides at the river's mouth now only rise 3 or 4 feet, and at springs 8 or 9. Thousands of acres have been reclaimed in consequence, which are interspersed with upwards of sixty fresh water lakes, varying in depth from 10 to 30 feet, and in extent from 1 acre to 1000. The Yare passes through some, and by depositing its earthy matter tends to render them a productive soil, if the sea does not again break in upon them, which sooner or later must be the case, as the shore about Yarmouth is constantly wearing away by the current which sets on it from the north-west, preventing any permanent delta from forming on this coast.

The Waveney, which separates Suffolk from Norfolk, is navigable for 25 miles to Bungay; and the Yare, which also empties itself here, for 22 miles is navigable to Norwich.

Wells, a small sea-port town on the coast of Norfolk, possesses a good harbour with a deep channel, but difficult of access, in consequence of the shifting sands. About the year 1719 the river which constitutes the harbour was improved, and a considerable quantity of land, redeemed from the marshy state, was rendered valuable for agricultural purposes by embanking it, and preventing the sea from any longer overflowing. Holkham marsh, including the creeks, consisting of 560 acres, was embanked at the expense of Lord Leicester, and 108 acres, called Wells marsh, at the expense of Sir Charles Turner; soon after, upwards of 1500 acres more were reclaimed; and in the year 1738, immediately below the town a sluice was formed called Friestone, after the name of the builder; it was constructed with fascines, stakes, piles, &c.; these in a very few years went to decay, the mouth widened, and it became necessary to reconstruct it, which was effectually done in the year 1765, when the harbour and channel down to the pool or mouth, which opened into the German Ocean, were perfectly scoured.

This second sluice soon required repairs, in consequence of the timber of which it was composed being eaten by the worm.

In the year 1782, so much mischief had accrued, that it became necessary, to prevent the loss of the harbour, that something effectual should be undertaken, and Mr. John Smeaton was called in to report upon the best means of performing the necessary works. This engineer found that as long as the sluice had been maintained in proper order, it had answered the intention of clearing and keeping in good condition the whole of the harbour and channel which intervened between the mouth of the sluice and the upper or south end of the pool; that since its decay the pool had so filled up, that at low water there was not more than 6 feet

depth; and that about twenty years before this survey, the direction of the harbour out to sea was north-west, and that vessels could be easily brought, during all the time of flood, in the direction of the channel. The entrance had veered, so as to be north-east or north-

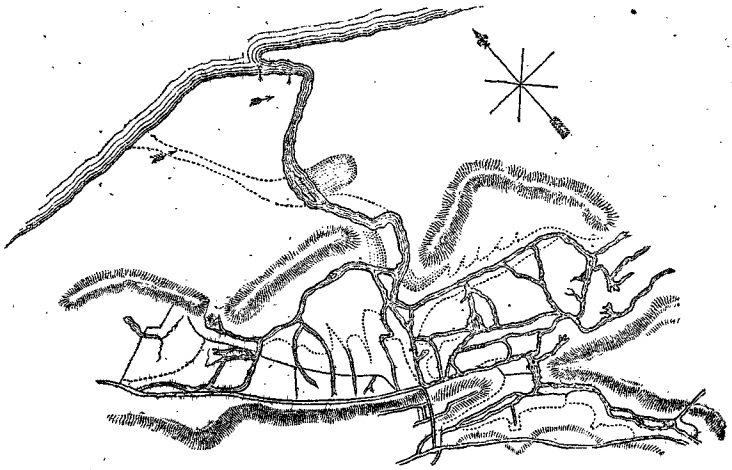


Fig. 324. WELLS-HARBOUR.

east by north, which rendered it difficult for vessels to enter. The distance from the quay to the channel was then between three or four miles, and the course of the waters was through broad and open sands, from the northward or out end of the pool to its outfall into the sea; the sand is perfectly clean, and so free from any particles of other matter that produce tenacity, that when dried by the sun it is moved easily by the wind, and is also considerably acted upon during storms; these sands now extend very considerably more in breadth than formerly.

Smeaton observed that the annual rains did not, in any way, increase the waters of the ocean, so as to cause it to swell its limits, exhalation raised by the power of the sun and winds keeping it at a constant level, but that the floods and rivers carried with them earthy matter, which was left either in the channels of rivers, or was borne out to sea; that these matters were not returned to the land, as water is by evaporation, but was left to a slow increase, and by the flux of the tides, and the agitation of the winds, was constantly in a state of motion, not only about the mouths of rivers, but in more distant parts; that there is no power of nature to return these particles of earthy matter to the coasts or high grounds, from whence they may have been disintegrated, and that, by their accumulation in the ocean, they must always be on the increase, and so continue, till the place of their reception is entirely filled up.

At one period probably the whole of this coast presented nothing more than a naked sand, lying against the bare shore, upon which the town of Wells now stands; in the course of time, the breadth of this sand increasing, and the declivity becoming too small for the tidal water left by the flood to make its retreat, so as to keep pace in its return with the ebb at sea, a body of water would be left behind, which having a sensible declivity towards the sea, made its way into the lowest slades, and there cut a gully, which was again enlarged by the influx and efflux of the tide; a scour thus produced would keep the passage open, by letting a certain quantity of water in and out; but the breadth of the sands gradually increasing, a greater body and surface of water would require a passage, which would increase its power of scouring: the gully by this means would be widened into a fleet or creek in the course of time. By this process, the sand furthest distant from low water being mixed with clayey matter, brought in by the tide, is on the constant rise, and after the salt water has left it, and it has been some time exposed to the action of the sun and air, the surface is fitted for vegetation, and in time becomes a salt marsh.

These marshes at Wells having increased in height as well as in breadth, a greater body of water is left upon them; the gullies or creeks multiplied with the increase of breadth, and the larger ones increase in size and depth: at Wells, these having been collected into one now serve to scour the channel.

The marshes increasing in breadth and height have a greater surface of water upon them, but not an increased depth; and yet, there is more water requiring a passage to the sea than before; for as long as the depth of water is considerable upon these salt marshes, the water makes its way to sea, by settling gradually, and passes off, in the nearest direction over the marsh surfaces, without having any need for the gullies and creeks as drain. The last foot in depth, over the whole surface, is what produces the scour, in the several gullies; and this is increased to a great degree, in consequence of the water having retreated from the gullies, and allowing the full force of their draining off to operate upon their channel.

Whilst the neap tides were suffered to cover the surface of the marshes, the scour would be on the increase, and the harbour improved; but as soon as this scour was diminished, the gullies would become choked up, and the harbour in proportion injured.

The elevation of the surface of the salt marshes, from the fresh deposit of mud at every time they were overflowed, would not stop at the neap tides, but would gradually rise higher and higher towards the high water of spring tides, until they became so high that no embankments were necessary; and the same effect would happen in all the creeks and gullies, which would elevate their beds in the same proportion. The surface of the marshes, rising higher and higher from the neap to the spring tide mark, they became less overflowed, and the gullies, not having so much water down them, would grow less capacious; the creeks would suffer from the same cause, and eventually the main channel. The tide water, however, at the same time flowing in through the creeks and gullies to the several extremities of its branches, must flow back the same way, and their extremities would be the first to silt up; this progress continuing, and there being no natural tendency at work as a remedy, it alone could be changed by employing human ingenuity and labour. The harbour of Wells was kept open by the reflow of the tidal water, or, as it is called, the back water; and whatever has cut off or diminished this has been a detriment to the scour, and to the maintenance of the channel.

When a backwater, assisted by a large freshwater river, makes its way through moveable sands, its direction will be that where there is the greatest declivity; and if that happens to be in the shortest direction, it has no natural tendency to gain a longer course, which would necessarily lessen its force; and wherever we find water flowing in a course that is not the shortest, we may conclude that it has a more speedy descent in that direction than in any other, and thus it is that many streams have a meandering course. "The bar at the mouth of the harbour appears not to have been noticed by Smeaton, as of much importance to the hindrance of the navigation, nor did he fancy that it formed any injury to the entrance for the shipping. Between Hunstanton and Weybourne on this coast are numerous low dunes or hills 50 or 60 feet in height, which are formed along the shore, and are composed of blown sand; these in the course of time are united into a solid and compact mass by the roots of the Marram, or Arundo arenaria; and such is the present set of the tides along this shore, that the harbour is now securely defended by these natural barriers.

"The harbours of Wells, Clay, and many others, are defended from all encroachments by the ocean, by such deposits which have entirely altered the contour of the coast.

"*King's Lynn Harbour* was a place of importance at the time of the Norman conquest. It is situated on the Great Ouse river, where its breadth is very considerable; the town is on the eastern bank, at a distance of about 10 miles from the ocean, and four small rivers or fleets divide it into several parts.

"Mr. John Smeaton, who reported upon the state and improvement of this river harbour, in the year 1767, found that the course of the Ouse was in as good a condition as it had been described in former accounts, and that there was no material cause of complaint. A bar had formed itself on the upper mouth of the west channel, and the current at low water was confined to the east channel, which was proportionally improved in consequence; nature, in spite of all the objections made to the contrary, had taken this course, and Smeaton was not willing to propose any thing which should counteract her intentions.

"It had been suggested some years before to build two jetties, to prevent too much swell running into the harbour, which should serve also to remove the bar forming in the east channel; but Smeaton was of opinion, that where a channel must be maintained through a vast mass of sand, capable of shifting by winds, seas, currents, and other powers, the more directly the waters make their passage out to sea the better. Any check given to the indraught of the raging tides, which was complained of, would also check the moderate ones, and the greater the efflux, which in some measure depends upon the influx, the better the channel would be made and maintained. Too great tides may be a partial evil, though a fault on the right side, and in this, as well as in many affairs of human life, the judgment consists in choosing the least of two evils.

"It was not wise to affect the indraught of the tides, or to diminish the quantity of fresh water coming down the river from above, but to leave nature to do what was required; for

wherever there are many acting forces and disturbing causes, the goodness of the channel may by turns be better or worse; but the grand principles of preservation being maintained, after a wrong turn happens, a right one will succeed, as experience has shown in the present case; when nature tends rightly, leave her alone; it is time enough to help her when we are sure she is going wrong."

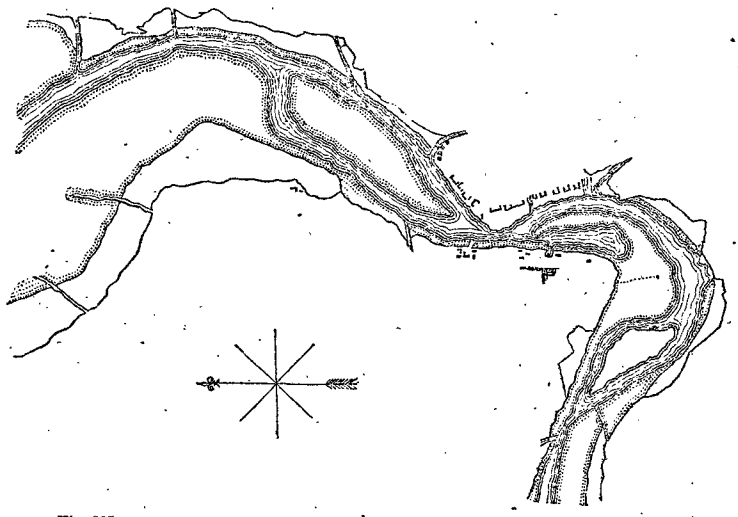


Fig. 325. KING'S LYNN.

Having already discouraged all attempts to prevent the free influx and efflux of the tides and land waters, in order to preserve the channel out to sea in the most effectual manner, upon which the navigation and drainage by the Ouse entirely depend, he then speaks of the banks of the river, and says that they ought to be made stout and high enough to stand against all extremes; he disapproves of all jetties built into the stream, as a defence for saving the banks and foreshores from the action of the water, as they seldom failed of producing a deep pit, either opposite to or on the downstream side of the jetty, which tends to undermine the banks as well as the jetty itself.

"All works attempted for the preservation of the foot or bank of foreshores, when too hard a set of the water tends to undermine them, ought to be disposed parallel, or according to the direction of the stream, so that the water, instead of being stopped or thrown off, shall glide gently by; with the least interruption possible; for thereby the water gets away with the least action upon the banks, and wears them or their defences the least. On this account, all angles and sudden turns should be avoided, and when a turn must be made, let it have as easy a sweep as possible, keeping it near to the natural bend of the river, cutting or rounding off all small sudden turns, angles or exuberances, which may happen in the general sweep.

"All jetties do mischief, and wherever the sides of a river or foreshore grind away by too great stress of water, the most infallible, secure, and lasting method of remedying this is, after the irregularities of the curve are taken away, as low as the water will admit being performed by hand, to line up the foot with rubble stones thrown in promiscuously so as to form their own natural slope against the shore, till they appear above low water. This being done, nature will form for herself such a slope to neap tide high water mark as will need no artificial defence.

"The base of the banks and foreshores being secured, and the slope being naturally formed up to the high water mark of neap tides, it will be then sufficiently defended against waves and currents; above this there is no better way of finishing the wall than by turfing it. No wood should be used at the foot of the turf about neap tide high water mark, but the whole reliance should be upon a lay of rubble stone, and if some of this be broken, to fill up the interstices of the larger pieces, this will form a more complete union between the rubble and turf than if composed of large stones only.

"Boarded wharfing is not calculated to stand long against the action of the waves, and soon goes to decay; when the sea dashes against the end of a faggot or a stone, these

having no solid connection with their neighbours, the impression goes no farther, but the tremulous motion raised in one part of a boarded wharfing is communicated over a large area, which in time loosens the earth behind, and, as the tides enter by degrees, brings the whole to ruin.

"Wherever the foreshores are not broad enough, from low water to neap tide high water mark, to stand by a natural slope, they should be reduced to a slope of two to one, that is to batter two feet to one perpendicular; and this being covered a foot thick with rubble stones of all sizes, bedded together and footed upon the rubble, thrown in to support the ground under low water mark, will make a lasting and durable defence, and will resist any ordinary force, but, if exposed to the waves of the open sea, the cover must be increased in weight and thickness. This method will answer if the batter is three to five, or even one to one, but the first inclination is preferable.

"Banks, to be secure against inundations, must not only be high enough, but sufficiently strong, and experience here is the best guide. They are proof only when they stand at least a foot higher than the level the waters are known to rise. It is not, however, necessary to preserve the same slope above the high water mark of equinoctial spring tides to the extremest height as below that mark, because they will seldom come to such a stress, yet they ought to be sufficient to answer if they are put to it.

"In order to do this, they should be at least 3 feet broad at the extreme height, and three times as much broader at the level of the equinoctial spring tide mark, as the extreme height exceeds their height.

"The artificial banks below that mark should be at least four times as much broader in their base or seat, upon the natural level of the ground, as the perpendicular height of the said extreme tide mark is above the natural level of the ground, whereon each part of the said bank stands: when the earth is loose, sandy, or moorish, the bases or seats and tops should be respectively broader."

The harbour has undergone considerable improvement at various times, since Mr. Smeaton was called upon to make his report, but the anchorage is not good, in consequence of the *oozy* bed of the river, which has several times changed its direction. The Great Ouse now carries its water by a new cut from Littleport Chain to Rebeck, and the Little Ouse is a narrow stream.

There can be no doubt that the harbour has sustained considerable damage from the obstructions, which prevented the ascent of the tides up the river; it is not a quarter of a mile in breadth at Lynn, though six miles below its width is four times as much; on some occasions the tide flows in so rapidly, that it has received the name of the Bore, and its violence frequently changes the curvature of the channel.

This town, distant ten miles from the coast, enjoys considerable commercial advantages, and by means of the Ouse and its tributary rivers communicates its navigation with eight counties; its inhabitants have received from various sovereigns as many as fifteen charters; four small rivers, called fleets, divide the town, which is surrounded by a deep ditch, flanked by a strong wall which originally was strengthened by nine bastions.

Wisbeach, the most northern town in Cambridgeshire, derives its name from its situation on the banks of the Ouse, or *Wis*, which flows through it into the sea, about 8 miles distance. All the waters, which were directed by a channel, cut in the reign of Edward I. to benefit Lynn, once passed through this place; the town, however, from its situation, carries on considerable trade.

Boston, situated on the Witham, about 5 miles from its mouth, is an important port of the gulf called the Wash; some few years ago the channel of the river was considerably deepened, and an iron bridge of a single arch, 86 feet span, designed by Mr. Rennie, was thrown across it; the width of the carriage way was 39 feet, and the abutments are so kept down, that there is not much rise from the horizontal direction.

The tower of the church, somewhat resembling that of the cathedral at Antwerp, 282 feet in height, has a lantern at top, which formerly served as a guide to the navigators of the Boston deeps.

The whole of the country around Boston is subject to inundations; in 1820, a high spring tide, accompanied by a violent tempest, broke through the sea embankment, and did considerable damage.

Grimsby, formerly the emporium resorted to by merchants from Norway and the western islands, had its commerce destroyed by the silting up of its famous harbour: this, however, has been partly improved, and a dry dock, constructed at a vast expense, has restored some of its former prosperity.

Barton-upon-Humber, about three quarters of a mile from its banks, carries on considerable trade, from its position on the Ancholme canal and the basin of the Humber.

Port of Goole, Yorkshire, is on the Ouse, at some distance from where it falls into the Humber, and near to where the Dutch river forms a junction with the former; this port, therefore, is considerably more inland than Hull, and has two wet docks and a basin. The

ship dock is 600 feet in length, and 200 feet in width, and will contain fifty-four sail of square-rigged vessels, seventeen of which can lie at the quay at the same time.

The barge dock is 900 feet in length, and 150 feet in width, and will contain 200 sail.

The basin is 250 feet by 200 feet, has a depth of water of 19 feet, and the timber pond is calculated to contain 3000 loads.

The warehouses are capacious for bonding goods of all kinds: it was made a bonding port in the year 1828.

A canal unites Goole with Ferry Bridge, at which place it joins the river Aire, so that Leeds and Wakefield are by this means connected.

Kingston-upon-Hull, was first made of importance by King Edward I.; when he returned from his expedition into Scotland, this monarch made inquiries concerning the depth of the river, the height to which the tides flowed, and afterwards sent for the Abbot of Meaux, who was lord of the soil, and exchanged some lands for what he possessed. The manor-house being converted into a palace, obtained for the town its royal appellation. A new harbour being formed in 1299, a charter was granted to the inhabitants of the borough, who constructed new walls around the town, 2610 yards in circuit, and of considerable strength. From this period the commerce improved, and the merchants became wealthy.

The old dock was the first constructed, an act for which was obtained in April, 1774. Previous to this period, the only harbour for vessels was that portion of the river Hull which extended from the North bridge to the end of the Garrison jetty, a distance of 2940 feet, and the width at high water of spring tides averaged about 165 feet; the total

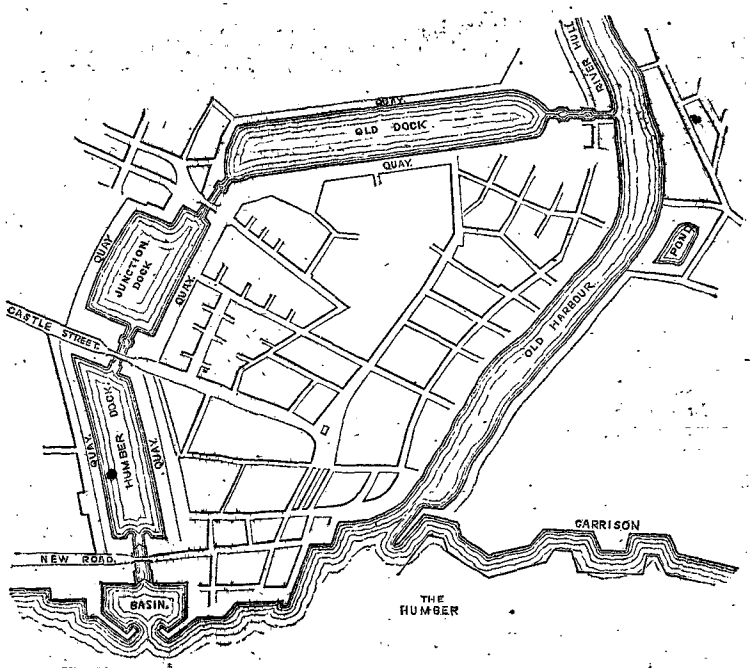


Fig. 326. HULL DOCKS.

area might be estimated at 11 acres, the depth of which was 22 feet. This harbour was found inadequate to the growing trade of Hull, as well as inconvenient, from the violence of the stream some hours before low water preventing vessels from coming up; the fall being from 4 to 5 feet, from the outer end of the old dock basin to the harbour mouth, and the velocity of the ebb from 3 to 4 miles per hour.

The old dock, formed under the superintendence of Mr. Grundy, the engineer, is in length 1703 feet, and in width 254, containing an area of nearly 10 acres.

The walls are of brick, coped with stone from Bramley Fall; and in front, at every 10 feet, are oak fenders, 9 by 7½ inches, tenoned into three oak sills, 12 inches by 6; these are

built into the brickwork, and secured by oak brackets on each side, as well as by strong iron bolts.

The walls are built upon longitudinal sleepers, 12 inches by 6, laid flat, and trenailed on to pile heads; across these are laid 3-inch planks, all of fir timber.

The piling having given way, and the walls bulged out in some places, a great portion was obliged to be rebuilt.

Lock and basin. The original lock, 36 feet 6 inches in width, 24 feet 6 inches deep, and 200 feet in length, was built upon a wooden floor; 4-inch planks were laid upon transverse and longitudinal joists, bedded on 1245 bearing piles, 12 feet in length: across the lock were six rows of grooved sheet piling, 14 feet in length. The walls, constructed of brick, were faced with Mexborough stone, and the hollow quoins and coping were of Bramley Fall, all set in puzzolana.

The basin was constructed in the same manner, and was in length 212 feet, and in width 80 feet.

The entrance lock and basin, in the year 1814, was entirely rebuilt, under the direction of Mr. Rennie, the old one having become decayed. After the water was drawn out of the dock to within 4 or 5 feet of the bottom, a coffer-dam was made at the outer end of the basin, next the harbour, and a dam of clay on the side next the dock, and the lock and basin walls were removed, when the piles, sleepers, and planks were found perfectly sound, although in many places the foundations had considerably gone down.

The new lock is 120 feet 9 inches in length, within the gates, 38 feet wide at the top, and 24 feet 6 inches high, above the sills.

The inverted arch is brick laid in puzzolana, as well as the side walls, which were faced with Bramley Fall stone; the lowest course was all headers, 4 feet in length, and 18 inches in thickness. The hollow quoins are of Rotherham stone, and the coping of coarse sandstone from Bramley Fall, 15 inches in thickness, and 4 feet in width.

The gates are constructed of English oak, except the planking, which is of fir, 2½ inches in thickness. They are each 23 feet wide, 24 feet 3 inches high above the pointing sill, 16 inches thick at the heel, and 14½ inches at the head. There are 10 bars or ribs, slightly curved, tenoned into the heel-posts, and secured by iron straps and screw bolts.

The sluices are of cast-iron, 2 feet 6 inches square in the clear, and are worked by a wrought-iron screw and brass nut, with bevel gear at top.

To move the gates, at the side of the lock, is placed machinery which turns a cast-iron roller, round which is a revolving chain made of ⅞-inch iron; these chains are fixed from 2 to 4 feet above the bottom sill for shutting, and 7 feet for opening the gates; to assist the latter operation, there is a counterbalance weight, which prevents the chains from running off the roller.

In front of the lock walls, at about 10 feet above the sills, is placed one horizontal and two vertical rollers, with another large horizontal one, at the foot of each wall, around which the chain turns whilst working the gates.

The heel-post has a cast-iron socket at the bottom, 3½ inches in diameter, and 1¾ deep: this turns on a cast-iron pivot securely fixed on the bottom.

The brass friction roller, which moves on a segment of cast-iron, is 10 inches in diameter, and 4 inches in length, fitted into a cast-iron box or frame near the meeting post; to this is attached a wrought-iron regulating rod, which reaches to the top of the gate, to adjust the roller.

The bridge over the lock, of cast-iron, is 15 feet in width, the road for carriages being 7 feet 6, and the entire length 81 feet. It is formed of six ribs, 1½ inch in thickness in the middle, and 3 inches thick at the flanch; they are 9 inches deep where they meet in the middle, and increase a little towards the sides. The bridge turns on a cast-iron shaft, 8 inches square, with four round bearings, working in plummer blocks, fixed in cast-iron carriages bolted firmly into the masonry.

To open this balance bridge, a lever is applied to lift a cast-iron flap, which turns on an axis 4½ inches square: when this flap is lifted, the bridge rises, and the flap forms a barrier against passengers, and when the bridge is again lowered, it forms part of the roadway.

The bridge is covered with oak plank, 3 inches in thickness, bolted to the iron ribs, and where the wheels of the carriages pass it is lined with 1½ inch elm. The footways are also lined in the same way, and stand up about 5 inches above the road on each side, guarded by a cast-iron curb, and wrought-iron bars and chains.

As this bridge ascends, the outer end descends into a cavity, prepared for the purpose; and one man can raise or lower each portion in half a minute; its weight, exclusive of the timber, is about 80 tons.

Basin of entrance is 213 feet in length, 80 feet 6 inches in width at the top, and 71 feet at the bottom. It is cased with brick, and coped with stone from Bramley Fall; 14 feet from the bottom is a bond course of the same stone, passing through the whole thickness.

The side walls are supported by brick inverted arches, which are built across the bottom, 6 feet wide and 18 inches deep; the spaces between are 10 feet in width, and the whole is levelled down with earth to the top of the lock sills.

The Humber dock, in length 914 feet, and in breadth 342, was designed and completed under the superintendence of Mr. Rennie and Mr. William Chapman; the act of parliament for its establishment was obtained in 1802, and it was commenced soon after. It comprises an area of a little more than 7 acres. To keep out the tide, during the execution of the work, at the south end a coffer-dam was formed; its span was 280 feet, and its versed sine about 140. It was constructed of two rows of Dantzic piles, 7 feet 6 inches apart; the piles were of whole timber, and well bolted and braced together. In the middle, at the bottom, was a trunk, and in the space between the rows of piles, bricks laid in sand were built up to the level of high water. The perpendicular head of water pressing against it being sometimes 30 feet in height, shores and braces were required to counteract its efforts to drive in the dam.

The water was pumped out by a steam-engine of six horse-power, which worked two eleven-inch pumps; this engine also raised two rams of 7 cwt. each, for driving the various piles. After the water was pumped out, the excavation was carried to an average depth of 24 feet, the soil being alluvial and stiff clay. To excavate the basin, on the outside the coffer-dam, which at every tide was overflowed, horse-runs were established to remove the soil; and what could not be moved by this means was conveyed away in ballast lighters.

The foundations of the dock walls are piled, with a row of 6-inch grooved sheeting piles in front; the other piles are 9 inches and those under the counterforts 8 inches in diameter. To drive them, a ringing engine, with a ram of 4 cwt. worked by fifteen or sixteen men, was employed. On the heads of the piles were bolted longitudinal sleepers of half timber; and the sheeting piles were securely spiked to an inner waling of the same scantling. Over the sleepers was laid a transverse covering of 4-inch plank, on which was commenced the wall. The piles were of Norway and the other timber Memel. The dock walls were built of brick made out of the excavated clay, and where the bottom of the fenders terminate is a course of stone, 15 inches thick, passing entirely through the wall; and between the tides are worked three other courses, all of Barnsley stone. The whole is coped with stone from the same quarries, 15 inches thick, and 4 feet in width, the joints being secured by square dowels. Warmsworth blue lime and sharp fresh water sand were used for the mortar, the lime being previously ground dry, and afterwards mixed, and used hot.

The oak fenders to protect this wall are 12 inches square, and project from the brickwork 8 inches, the rest being sunk into the brickwork. At their feet they are dovetailed into stone corbels, and at the top they are secured by oak ties and wrought-iron fastenings. The two rows of horizontal fenders are 7 inches square, tenoned into the upright ones; and pieces are laid under and above them, of an angular shape, to prevent vessels catching as the tide rises or falls.

The entrance lock within the gates is in length 158 feet, its top width 42 feet, and its height above the pointing sills 31 feet. The average depth of water at high water spring tides is 26 feet, and at neaps 20. The foundations are built upon four rows of bearing piles, with two others under the counterforts. These piles are from 15 to 20 feet long, and on the heads is securely bolted sleepers of half timber, laid longitudinally. These are again crossed by others of the same scantling, laid on edge, and the interval covered with 4-inch close planking; the spaces between are filled up with solid brickwork, on which is constructed the inverted arches and the side walls.

Across the platform are five rows of 6-inch grooved sheeting piles, from 15 to 20 feet in length; the bearing piles are distant about 3 or 4 feet each way; on these lay longitudinal sleepers, 12 inches square, with two courses of transverse sleepers close together, for 13 feet in length, from the main sill, on which the pointing sills are bolted. The other part of the platform is covered with 6-inch close elm plank, into which the cast-iron segments in which the gates traverse are sunk. At the tail of the lock is an apron, about 50 feet in length, covered with 4-inch plank; this is spiked to the transverse sills, which are bolted to the heads of the bearing piles; the outer end is protected by a row of 6-inch grooved sheeting piles. Norway timber was used for the piles, the planking is of Dantzic, and the pointing and main sills are of English oak.

The side walls have six counterforts on each side, each 6 feet square; the walls are in width at the top 6 feet 9 inches, and are built of brick, faced with stone, from Bramley Fall. The hollow quoins are of stone from Dundee, and for some length a part of the wing-walls are faced with the same material. A Bramley Fall stone coping, 13 inches thick, and 4 feet wide, terminates the wall.

The lock gates are in height above the pointing sills 31 feet 4 inches, and in breadth 25 feet 6 inches, measured on the curve; they camber 14¾ inches. At the head they are

in thickness 14½ inches, and at the heel 16½ inches; each gate, which may be considered a solid mass of oak timber, the planking only being fir, has two cast-iron sluices, 3 feet square, with a rod, worked at the top by an iron screw.

To open and shut the gates, there is a 6-inch iron pinion, which works in a cog wheel, 4 feet diameter, round the cast-iron axis of which the gate chain winds.

Over the centre of this lock is an iron swivel bridge, in length 81 feet 9 inches, and in breadth 12 feet 3 inches; it forms a segment of a circle, and meets in the middle. It is composed of six cast-iron ribs, 2 inches thick at top, and 2⅓ inches on the lower edge, united and braced together, and covered with 2½-inch oak plank. A cast-iron plate, 11 feet 9 inches diameter, is firmly bedded on a pier of brickwork on each side: this has a pivot in the centre, which works in a socket underneath the bridge; revolving between this circular plate and another on the underside of the bridge are twenty conical rollers, 10¾ inches in diameter at one end, and 9¾ inches at the other; these are 6 inches long, and are fitted into a frame. A man can open and shut this bridge by means of the machinery attached, which consists of two 8-inch bevel pinions, one of which receives the handle; at the bottom of the other is a vertical shaft, which has fixed on it a 9-inch pinion, which works in a spur-wheel, 4 feet in diameter; on the axis of this is another pinion, 12 inches in diameter; this works in a toothed segment at the outer end of the bridge, and turns it.

The entrance basin to this dock, 267 feet in length, and 435 feet in breadth, has its walls constructed in a similar way to those to which it belongs; at the top they are in thickness 6 feet, at the bottom 10 feet; they are faced with stone from Bramley Fall, and have a similar coping. The walls rest on three rows of piles from 16 feet to 18 feet long, and in front is a row of sheeting piles, with transverse sleepers, closely planked over.

The mooring posts are placed 30 feet apart, and about 12 feet from the sides of the lock.

The Junction Dock, 645 feet in length, and 407 feet in breadth, was commenced in 1826, from the designs of Mr. James Walker, and contains an area equal to 6 acres. Two coffer-dams were employed; that next the Humber dock was 220 feet in length, forming a curve, the versed sine of which was 61 feet. It was formed of two rows of close piles, 6 feet apart, and after the mud was taken out, filled in with well puddled clay: the piles were of whole timber, about 40 feet in length. In front, on each side, were forty-two gauge piles with two rows of waling pieces, 13 inches by 8, well bolted. Rough iron tie rods were also introduced to prevent the work from yielding; against this dam was a pressure occasionally of 28 feet of water, which found its way along the cross braces, but was speedily stopped.

The other coffer-dam, at the west end of the old dock, a curve of 115 feet in length, with a versed sine of 14 feet, was formed in a similar manner.

The water was pumped out by two six-horse steam-engines, and the sides of the dock were excavated with a slope of one horizontal to one vertical. The average depth of the excavation was 19 feet, and the quantity of clay and earth removed was about 300,000 cubic yards.

Under the dock walls were driven 2401 piles, containing 18,500 cubic feet of timber, and 2140 feet in length of sheet piling, 12 feet in depth, and which cubed to 12,840 feet; on the heads of some of these piles it has been calculated there is a superincumbent weight of 20 tons.

Below the sleepers, the space is filled up with brick rubbish puddled or grouted with hot lime and sand, and at the foot of the wall is a similar bed of concrete.

The wall is of brick, partly faced with Bramley Fall stone, in 12-inch courses; this extends from the coping about 11 feet 9 inches downwards; the two lowest courses are, however, of stone from Barnsley or Whitby, both fine sandstones, and each 15 inches thick; every two stretchers have one header, which are each 3 feet 6 inches long: the whole is coped with similar stone, 4 feet in width, and each joint is secured with a 4-inch square dowel.

The walls are curved about 7 feet on the east and west sides.

The locks within the gates are in length 120 feet, and in width at the top 36 feet 6 inches: they are in height above the pointing sills 25 feet.

The lock gates, formed of English and African oak, are cased with 3-inch fir planking; they are hung at top with a wrought-iron collar, in a cast-iron anchor, let into the stone-work; the heel-post has an iron socket, which turns on a brass pivot; the outer end of the gate is supported on a brass roller, 12 inches diameter, and 4 inches wide; to this is attached an adjusting screw: the roller moves in a brass segment, let into and screwed down to the platform. To work these gates, on each side is the machinery, which is fixed into a cast-iron box; it consists of a 7-inch pinion, which works in a spur-wheel 4 feet diameter, on the axis of which is a cast-iron roller, 3 feet long, and from 12 inches to 9 inches diameter; a three-quarter inch chain winds round this, and passing under a roller at the bottom of the wall, and over another, in the face of the walls, is fastened to the gate. There is attached, as in the other locks, a counterbalance weight and chain. Each gate

weighs upwards of 20 tons, and has two sets of sluices, working on brass facings, in iron grooves, and so constructed that one set is raised whilst the other is lowered; this is effected by having the sluice rod attached to a rack that turns a spur-wheel working in another rack attached to the other sluice rod; thus a capacious opening is obtained without weakening the gates.

The bridges over are on the balance or lifting principle, and are moved by means of four crabs, two on each side; the handle is applied to a 6-inch pinion, which drives a spur-wheel 4 feet in diameter, on the axis of which is a 12-inch pinion, working in a toothed segment, the radius being 5 feet 9 inches; this is attached to the outer rib of the bridge. Each bridge weighs nearly 100 tons, and it can be opened or shut by three men in less than a minute.

Cleansing the Docks of the mud deposited by the waters of the Humber, is a matter of considerable moment, as it is said the quantity annually deposited in the Humber Dock was 36,000 tons. The dredging machine employed is placed on a flat-bottomed vessel, 80 feet in length and 20 feet in breadth, drawing 5 feet water. It is worked by a steam-engine of six-horse power; its stroke is 2 feet, forty times a minute; by means of a bell crank, motion is given to four cog-wheels; on the axis of the upper one is a square tumbler, with a corresponding one at the lower end of the bucket-frame. There are twenty-nine iron buckets, revolving on an endless chain, which deposit the mud they bring up, by means of a spout, into lighters. This endless chain turns on an axis at the upper end, and the lower end passes through an opening in the middle of the boats, and is raised or lowered by a crab, and tackling fixed over it; by this means, the buckets are placed at the proper level for dredging. An engine man and three assistants are required to manage this machine, and two others to attend the lighters. Sixty tons per hour is sometimes raised, but usually twelve boats, each of 500 tons, are employed, and the ordinary work performed is about 45 tons per hour. The mud boats are flat-bottomed, and draw 4 feet water; they are in length 48 feet in width 17 feet 6 inches, and carry about 40 tons.

The tide basin is scoured by two cast-iron mains, 4 feet in diameter next the lock, and diminishing to 2 feet 6 inches. At the outer end, branching out of these on each side, are ten 18-inch pipes, which discharge through the basin wall, about 5 feet above the level of the sills; other mains are connected with the docks, but they only scour where the water is discharged, and leave the bed in furrows, to be cleared away by other means.

In consequence of the waves of the Humber acting with violence against the outer gates of the dock, it was found necessary to build two piers to protect them. The main piles are 14 inches square, the outer waling the same scantling, and the inner wales 12 inches by 6; the cap sill 12 inches by 10; joists 7 inches by 4; ties 12 inches by 6; sheet piling 6 inches in thickness, and the planking 3 inches in thickness.

Spurn Point Lighthouses were commenced near the Humber mouth by John Smeaton, in the year 1771; they were built of brick, and his instructions were to make the largest 90 feet in height from the mean surface of the ground to the centre of the light, and the smallest 50 feet high; both were to be provided with inclosed lanterns for fire-lights.

The original lighthouse was a strong brick building of an octangular form, 60 feet high: the light was hoisted on a *swape*, a provincial term for a lever, fixed upon a centre which could be turned in any direction by the hand. A naked coal fire was employed, which

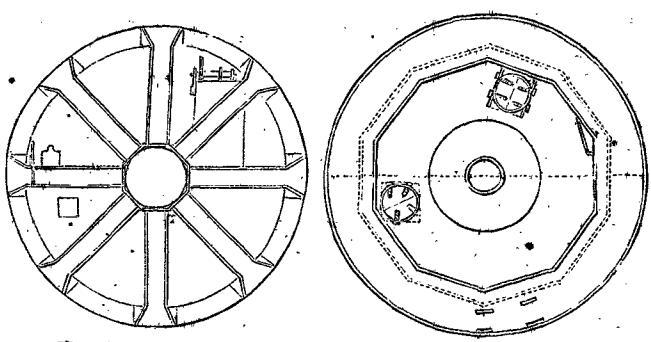


Fig. 227. PLANS OF SPURN POINT LIGHTHOUSE.

burnt with unequal force; during the storm of 1703, the draught was so great that it melted down the iron bars on which it was laid like lead. In the year 1777, the two new lighthouses were completed; in design they did not differ, but the lower one con-

sisted of fewer apartments, there being only a coal vault, a dwelling room, pipe room, and lantern.

In the larger one there was a coal vault, a smith's shop, and machine for hoisting the coals. A vacant room, a dwelling room, with two fireplaces, to be used according to the direction of the wind, two chambers, one over the other, a pipe room, wherein were two of the eight pipes that conveyed air from the external hopper mouths to the receptacle, which was lined with thick plate iron; the bottom being stone, when the door was shut, the air ascended through a large funnel and the hearth to the fire-grate.

The flame was seen in every direction, through the windows of the lantern, and the smoke was collected in its passage through the decagon conical roof, composed of ten Elland edge flag-stones, and then through the copper funnel at the top.

The coals to supply the fire were drawn up in a tub through an opening by means of a roll, wheel, pinion, and wrench. A rope from thence, ascending through all the floors, passed over a large pulley suspended from the roof, and thence downwards through the hole in an arch to a large square wooden pipe, terminating in a hopper mouth, proper for receiving the burthen.

The ashes and hot cinders, passing through the grate, fell into the bottom of the receptacle, and by heating the air therein promoted a sufficient draught in the calmest weather, which could be augmented and regulated, when there was a breeze, as any of the air-pipes could be enclosed at pleasure. The ashes and cinders were thrown into a

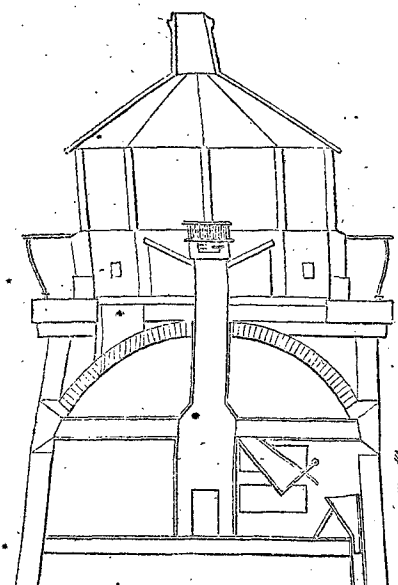


Fig. 328. SPURN POINT

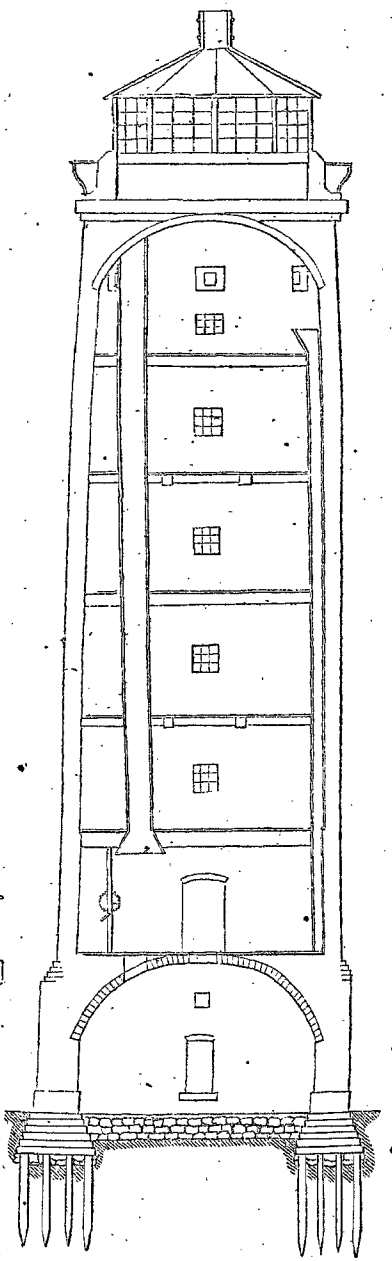
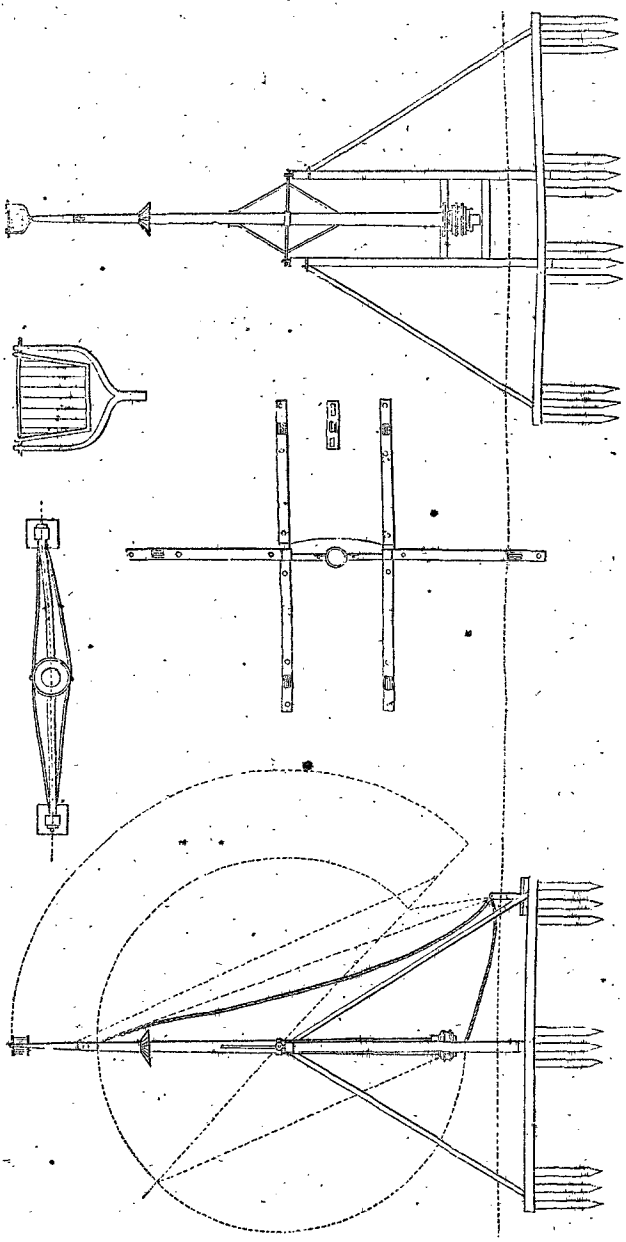


Fig 329. SECTION OF LIGHTHOUSE.

hopper, and conveyed down a square wooden pipe, through a funnel formed in the brick-work, and from thence into a bingstead in the court-yard.

The corner pillars of the lantern were of cast-iron, the sash frames of oak.



SPURN HEAD TEMPORARY LIGHT.

Fig. 330.

The year after the completion of the lighthouses, the lower one was washed away, and totally destroyed, when a new swape light was erected: in the year 1816 the coal fires

were discontinued, and a new brick building was erected, with lamps and reflectors. In the year 1828 this was destroyed, and a wooden tower erected further inland, which was removed, three years afterwards, 50 yards further inland, to avoid the encroachment of the sea.

The swape, including the walls on which it stood, exhibits at the height of 56 feet.

The fire basket of iron turning upon its axis places itself level, in every position of the mast. This loaded with a weight counterbalances the iron work and fuel at the top; the whole being steadied and clipped into an iron frame, that turns in equilibrio upon the horizontal axis, supported by pillars and braces.

To renew the fire, the attendant, laying hold of one of the winches of the roll, turns it round, so as to wind the rope upon it, which, after going obliquely towards the ground, passes a pulley in a stud, fixed therein, at some yards' distance, and thence rising obliquely upward, it lays hold of the mast by a small chain.

By the motion of the roll the fire basket is brought to the ground, where it is fed with coals. While the rope is winding upon the roll, the rope, being coiled thereon the contrary way, was unwinding; and this being attached to the extreme of the lower end of the mast, and at equal distance, in rising carries the rope with it. The fuel being renewed, the winch is turned the contrary way round, by which that end of the mast is brought down, and the fire basket carried up into the position shown. The lower end of the mast is steadied against the cross piece, the roll being then fastened.

The projecting part is a small umbrella of sheet iron, to throw off the cinders.

Bridlington Quay opens directly upon the harbour, which is formed by two piers, extending a considerable distance into the sea; that to the north is a promenade, from whence a fine view of Flamborough Head and the spacious bay is obtained. South-westerly winds occasion a considerable deposit here, and the force of the waves is very much broken by the Smithick sand, which extends in a direction nearly north-east and south-west across the bay, on which there is only from 12 to 20 feet of water at the recess of the tide.

Scarborough is the only port on this coast, between the Humber and Tynemouth haven, where ships can find refuge in violent gales; it is easy of access, and has a sufficient depth of water at full tide for vessels of considerable burthen. As there is no natural stream to scour the harbour, it is subject to be warped up by the sand which is deposited in it, and is only cleansed by the violent agitation of the sea, produced by the strong gales from the east. Quay Street once bounded the old harbour, and is now only reached by the water at high spring tides, which proves how much deposit has taken place.

Whitby, at a very early period, had timber piers for the protection of its shipping, but it was not till about 1702, when two acts of parliament were obtained for the improvement of the port, that the present east pier was built, 200 yards westerly to the channel of the Eske, which affords a great security against the violence of the sea, when the wind is at north-east, which flows over the rock with a strong current into the harbour. About the same time, a staith was erected on the west side of the river, the Scotch head built, and the western pier formed, which extended 200 yards towards the sea, contiguous to the channel of the Eske.

The sand that daily warped into the harbour, around the west pier, and the bed of sand that continually lay at the head of that pier, seemed to threaten its destruction, when it was proposed to lengthen the pier on the west, and extend it sufficiently towards the north, that its head might shelter the east pier from the run of the sea, setting along the coast. An act of parliament was obtained to carry out this project, but it was only partly effected. The western pier is regularly built of stone, brought from a quarry near Woodlands, four miles south-west of Whitby, and extends 520 yards into the sea, where it is terminated by a circular head. One of the other piers, which extends from the east cliff, so contracts the entrance, that in hard blowing weather the harbour is difficult of access.

The town is built on two declivities, on the banks of the Eske, which empties itself into the harbour; a drawbridge is so constructed, that the inner harbour can be entered by vessels of 200 tons burthen. There are several dry docks, and ship-building is extensively carried on; the depth of water in the harbour at neap tides is 12 feet, at common tides 18, and 24 in the great equinoctial springs.

Hartlepool, situated on a promontory, is nearly surrounded by the German Ocean, and in front is a capacious bay, favourable for the reception of vessels at all times. "Few places," says Mr. Hutchinson, "give so perfect an idea of the fortifications of a former period; a long extended wall, strengthened by demi-bastions, are placed at intervals, some rounded, others square; various gates and sally ports, secured by machicolations and the portcullis; some of the gates defended by angular, others by square turrets, all the variety of style appearing as they had successively grown into use." As the wall runs along the edge of the creek, behind the point of land which projects into the sea, and from thence turns to cross the isthmus to the opposite cliff, the figure it forms is not regular, giving first a triangle, and then running with a sweep or bend north and eastward.

At the ness end or north-east point of the wall to the sea, it finished with an acute angle, rising on the brow of lofty rocks; the foundation has of late years wasted by the washing

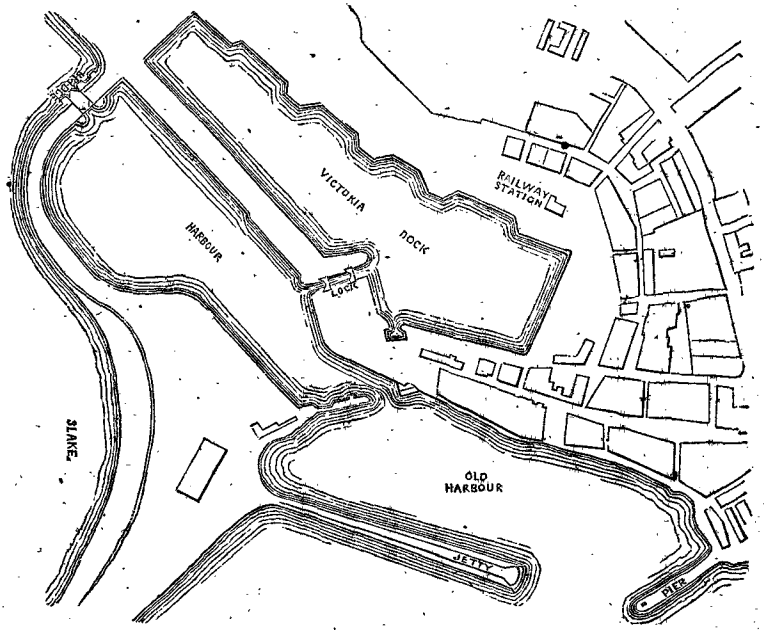


Fig. 331. HARTLEPOOL.

of the waves, and that part of the wall has now fallen; it was exactly similar to the ness or point of the Roman wall, opposite to the castle at Carlisle. The whole of the wall is much broken for a considerable distance from the sea. At about twenty paces are the remains of a square bastion; from thence about forty paces is a round bastion, projecting from the wall, about two-thirds of a circle, in girth nearly 30 feet: in the front of the bastion, at the distance of about 5 yards, is a high ridge of earth, probably cast up by assailants. From the second bastion, at about 40 paces, is a square bastion, about 10 feet in front, and projecting about 7 feet from the line of the wall; from thence, at 46 paces, is a second bastion somewhat larger than that before mentioned, making a projection of about 10 feet, not so prominent as the others. In all the portion described, the wall forms a straight line, the ground gradually inclines, and falls from the edge of the cliffs; where the wall begins at a distance of 30 paces, it forms an obtuse angle, guarded with a turret or bastion, from whence is a kind of horn work, projecting into the field for a considerable distance, of an angular figure, having two terraces, one above another, with the remains of the glacis, the mason's work appearing through the broken turf; from whence there is an extensive prospect of the sea and coast towards Sunderland, commanding Hawthorn Hive, or the Beacon Point, Essington, Elwich beacon, and a long tract of country. Thirteen paces from the angle, there is the appearance of a sally-port; but the wall has been repaired and altered in modern times, so that it is not possible to ascertain more concerning it. At the distance of about 60 paces is a round bastion, and 80 paces further, the great Land gate, the chief entrance of the town from Durham, opening upon a road, formed over a level marsh, easily broken up or flooded in a siege. This gate seems to have been strengthened by a wet ditch, and probably a drawbridge.

The whole wall, towers, and gateways are of excellent masonry, built of limestone, of so soft a nature in the bed or quarry, that it may be squared with an adze, but when exposed to the air becomes remarkably hard and durable: the arch of the gateway is ribbed, and besides double gates had a portcullis; the width of the passage is 10 feet, and of the whole gateway tower about 30 feet; the projection is not much above a foot from the face of the wall; it appears to have had a strong tower for its superstructure, entered at each side from the parapet of the wall. The approach to the town from this gate was by the side of the haven, which must have made a fine appearance; as the basin, if we may judge from the

present slake or morass, consisted of several acres, where a hundred sail might be moored. From this gateway commences the wall, which secured the haven, and runs in a direct line, the water at high tide coming up to the gate. It is somewhat more than 8 feet thick, faced on each side with dressed stone; the parapet is guarded by a breast-wall and embrasure, now greatly decayed. There is a water gate in the wall, formed by a low pointed arch, above 24 feet in span, and 10 feet high, for the small craft to pass in and out of the haven, without removing the boom chains afterwards noted; the gateway projects from the wall about 18 inches; it has had flood gates, and also a watch tower, as we apprehend from the remains of the superstructure. From thence, at about the distance of seventeen paces, is a square bastion about 8 feet in front; and nearly a hundred paces distant is another square bastion, and from thence about seventy paces is a lofty round tower, remaining very perfect, save the parapet and embrasures; opposite to it, at the distance of 36 feet, stood another tower, exactly similar in dimensions, as the fascia and foundations plainly show. This was the grand entrance into the haven, and by the space between the towers one may judge of the size of those vessels which were moored therein, a thirty-gun ship being 32 feet wide.

This entrance was guarded by large boom chains, stretched from tower to tower, the remains of the hoops belonging to such chains being still visible in the walls of the tower. At ten paces distant are the foundations of a round bastion, near which is a modern gate, where, it is presumed, was formerly a small doorway, for the convenience of persons landing from boats; at 24 paces distant the wall forms an angle; this angle is defended by a half moon.

The entrance into the haven had the peculiar security that vessels coming from the sea must necessarily double the cape or point of the isthmus, and then proceed along the whole range and stretch of the south wall, within reach of the engines and instruments of war, and pass the half moon which guarded the angle of the wall. At the distance of 60 paces from the angle is a square bastion, and near it is a large breach in the wall; from the square bastion, about 120 paces, is a round bastion, and next stands the gateway, now called the water-gate, which only communicates with the land at low water, and leads to the High Street; the arch of this gateway is pointed, about 8 feet in width, and defended on each hand by angular terraces, with fronts projecting, a figure not commonly met with in old fortifications. From this gate the wall advances to, and abuts upon, the rock near its point, where the pier and mole begins; the whole of this south part being much more modern than the north and west sides."

Bishop Pudsey, in the year 1189, probably raised the walls and increased the fortifications of Hartlepool, and by the Normans it was always held as an important place of security.

The docks were greatly improved by the late Mr. Rennie; a considerable sum of money has since been expended upon them, and they afford us now one of the best examples of a sluicing harbour that exists. The eastern dock next the entrance is 460 feet wide, the west dock 230 feet wide next the entrance, and 1075 feet in length, and the tidal harbour upwards of 700 feet in width, between the slake bank and quay wall.

The scouring sluice and tunnels between the slake and the tidal harbour were built in a most admirable manner; the channel for the water was 15 feet in width, having a flat arch at bottom as an invert, 22 inches in thickness, and another above, to cover the watercourse, 2 feet 3 inches deep, rising about 18 inches. The height of the side walls, between the springing of the top and bottom arch was 4 feet, and their thickness 5 feet 6 inches. The side walls, throughout their entire length, were further strengthened by external buttresses, 3 feet 6 inches thick, and 4 feet projection.

Sheeting piles were driven in at each end of the sluice, and also under the sluice gates or paddles. The entire foundation of the tunnel was floored with 3-inch plank, laid on stout timbers. The gates of the sluice are of cast-iron, lifted by well-arranged machinery, and the whole is made to operate most effectively.

The retaining walls have a curved face, the radius from which they are struck being 80 feet. The toe of the wall in the interior of the dock is 5 feet below low water, and those of the quay next the tide harbour 7 feet. The exterior quay walls are founded on piles, well protected, and carried up with excellent stone in regular courses, and coped throughout with stone 3 feet 6 inches in width. Oak fenders, 12 inches by 10, are fixed opposite each counterfort, at a level of 6 feet above low water, strong iron shoes being cast to retain them.

The retaining walls of the docks are at the base 12 feet in width, and diminish gradually to the top, where they are only 6 feet in width. The tops of the fenders are capped with cast-iron bollards; holding down stones, with Lewis eye-bolts, are everywhere provided for the fastening of the hawsers in a perfectly secure manner.

The bank wall between the tide harbour and the slake has a slope 4 to 1 next the tide-harbour, and 2 to 1 next the slake or reservoir, with a puddle wall carried up in the interior to prevent the water percolating.

The frames of all the sluices are made of cast-iron, as are the sluice gates.

There are also some admirable cast-iron turning bridges, 45 feet 6 inches span, which work upon pivots and conical rollers, about 9 inches in diameter; each leaf of these bridges is made to open by a sector rack, attached to the tail plate of each leaf, having a pinion with a spur and pinion, working into each other.

Sunderland, 20 miles south-east of the town of Berwick-upon-Tweed, occupies the right bank of the mouth of the Wear, and Wearmouth the other, and the two towns are united by an iron bridge of 236 feet span, and 98 feet from the underside to the level of high water.

The Wear is not navigable to Durham, as it is not swelled by many tributary streams.

From Sunderland bridge to the sea, a distance of a mile, the Wear forms an extensive dock, which is full of vessels engaged in the extensive coal trade carried on here. This is kept constantly open by the dredging machine, and there is a floating dock formed with convex gates; where the river empties itself into the ocean, the passage is confined by two piers, and from the force with which the tidal water mounts, there is never any obstruction at the mouth. The piers are composed of stone, laid in short horizontal courses, terminated at equal intervals by vertical timbers, so that if any part is broken through and carried away, it can be easily repaired.

At the end of the southern pier is a lighthouse, built of timber, and at the distance of 90 feet from the point of the north pier stands the great lighthouse.

The entrance to the harbour lies east-north-east; and on the eastern side is a ledge of rocks, which extends a quarter of a mile to seaward; this is covered at high water; the harbour is sheltered on all sides, except from the north-east.

The tide ebbs about 100 yards from the head of the north pier, and the harbour is dry at low water; spring tides rise about 18 feet; between the jetties at the entrance there is 6 feet at low water; neap tides rise only 9 feet, at which time there is only 6 or 7 feet water in the harbour.

Removal of the Lighthouse at Sunderland. — This building, which is octagonal on the plan, is of stone; its height is 62 feet 2 inches from the base to the cornice, and the lantern above was 16 feet, making a total height of 76 feet 2 inches. Its breadth at the base was 15 feet, and it diminished to 8 feet 6 inches. The lighthouse was erected in 1802, at an expense of 1400 pounds sterling; and in consequence of a breach made by the sea in the year 1841, it was required to be moved to a foundation prepared to receive it, a distance of 447 feet.

This operation was performed very successfully, in the following manner: — holes were cut through the stone walls on the north and south sides of the building, through which were passed six timbers, intended to be framed into a temporary platform. Where these main timbers came in contact with the masonry, they had spread over them a sheet of lead, to prevent their being unequally acted upon. Screws were then placed under these timbers, and they were forced to a bearing; after this upright timbers were introduced under them, and the screws were taken away. Four other timbers were then introduced, laid parallel to the first, which were screwed up and supported in a similar manner.

A hole was then cut on the eastern side, opposite the door, and through it were introduced two transverse timbers, which were firmly screwed to the others, and when shored up, the screws under them were taken away.

Timbers were then introduced with rails fixed to them; those in the centre, below the upper beams, were first fixed, and then bedded on the stone pavement around; the sheave balks to each were then threaded through the building, wedged to the timbers above, as well as to the rails below, by a series of wedges. The other rails and sheave balks were then similarly fixed underneath each timber, and when all the wheels were brought to a proper bearing, the stone work, which had been allowed to remain at four angles of the building, was cut away, and then two other timbers were introduced and secured.

The octagonal lighthouse had a three-inch plank from bottom to top laid against it at each angle, and these were hooped round with five iron hoops $2\frac{1}{4}$ inches broad, and $\frac{7}{8}$ inch thick; ropes and wedges were employed as well at regular distances, the whole made to embrace the building, and by means of screws were drawn closely up to the upright planks.

Under the cornice a hole was cut on each of the eight sides, where the walls were 10 inches in thickness; through these were pushed horizontal timbers from the inside, and these were drawn back until they met in the centre, iron plates covered the joints above and below the timbers, and screwed bolts passed through both.

This upper timber platform was connected to that below by a large chain, which passed round a strong bar of iron at the top, and another at the bottom, which was tightened by a screw. Eight upright timbers, a foot square, were tenoned into the horizontal timbers under the cornice, and brought close to the outer wall of the building, at the base, where they were secured by stirrup straps and bolts; these uprights were

united by three tiers of chock pieces; three iron straps passed round these as well as the uprights, and the whole screwed tightly together.

After this, raking braces were added, and the whole firmly bound together; then diagonal braces, to prevent the timbers from springing or twisting.

When the whole of these works was completed, five pulling screws were attached to the glacis of the pier, and the chains were fastened to them; 24 men were employed to turn these screws, four forcing screws, worked by three men at each, being applied behind the cradle to help propel. The total number of men employed amounted to fifty.

The platform or cradle that carried the whole weight, which was 338 tons, was supported on 144 wheels, which moved on eight parallel lines of rails.

The cradle timbers were of American oak, and all the rest was Memel; the cast-iron rails upon which the wheels moved were laid upon a plank of African oak 1½ inches in thickness.

There were employed, during the operation at the winches, 18 men, and their power may be estimated as equal to 562½ pounds. The radius of the handles of the winches was 14 inches, worked by a cog-wheel of 4½ inches diameter, turning a spur-wheel of 30 inches, and a barrel of 10 inches in diameter. The additional power of the two-fold and three-fold sheave blocks, made the whole power of the 18 men equal to 52,480 pounds, whilst the gross weight was 757,120 pounds.

The speed with which the whole was moved was about 84 feet per hour, when at the quickest; and the time occupied to move the whole distance was 13 hours 24 minutes.

The foundations prepared to receive the lighthouse after its removal were formed of solid blocks of stone, and when it had arrived over its destined position, the timber uprights were again wedged under its cradles, and the various sheaves and railway timbers drawn out. The masons then underpinned it by degrees, striking the upright supports as the building had obtained its proper bearing.

Mortar, composed of blue lias lime, sand, and puzzolana, was made use of, and great care was taken to pin up the last course; a sheet of lead being introduced to equalise the pressure.

Since its completion the works have stood remarkably well, and no settlement has taken place. The accomplishment of so arduous and novel a task as removing a lighthouse reflects the highest credit upon the engineer, John Murray.

From this port upwards of 1,300,000 tons of coal are annually shipped, and it is reckoned in importance the fourth port of the United Kingdom.

South Shields and *North Shields* occupy the banks at the mouth of the Tyne. Tynemouth, which is about 1½ miles distant from the former, has a lighthouse 61 feet high, which rises 168 feet above the level of the sea.

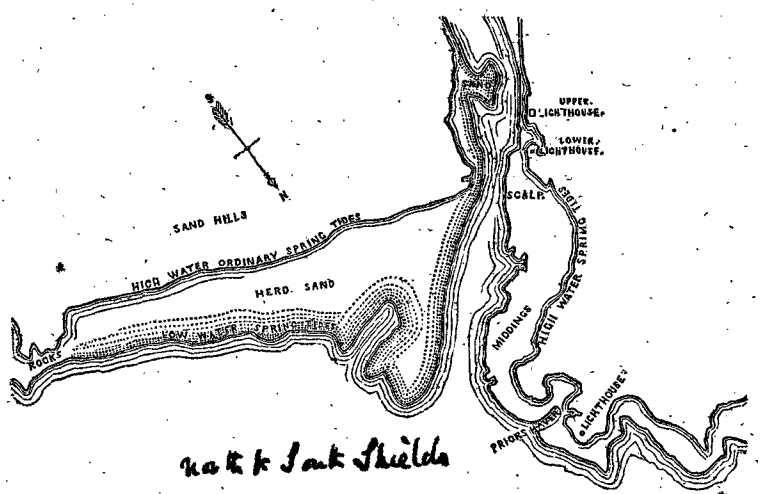


Fig. 332.

Newcastle is situated on the Tyne, and on the banks are many yards for ship-building. The average rise of the spring tides at North Shields is about 14 feet, at Hepburn

about 12, and at Newcastle 11 feet 6 inches. The velocity of the current of the flowing tides in springs above Shields is about 3 knots an hour at half flood, but about half ebb it is increased half a knot.

Jarrai Slake, which is covered at half flood, contains nearly 350 acres.

Berwick-upon-Tweed, is on the left bank of the river, and has a pier, erected under the direction of the late Mr. Rennie, at the end of which is a lighthouse. The harbour is by no means a convenient one; and the river, which is here crossed by a bridge of fifteen arches, is the second in point of importance to any in Scotland.

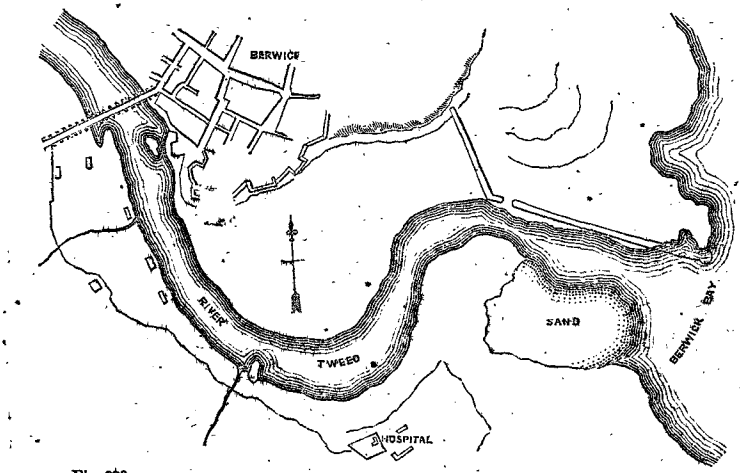


Fig. 333. BERWICK-UPON-TWEED.

Here, originally, was a pier, constructed in the reign of Elizabeth, which afforded shelter from storms from the north-easterly wind. Spring tides rise here about 15 feet, and neaps about 9 feet; and at high water of an ordinary spring tide, there is 19 or 20 feet water on the bar, and from 14 to 15 feet at the quay; at neap tides there is not so much by 3 or 4 feet.

Eyemouth Harbour, is advantageously situated at the corner of a bay, where ships can work in and out at all times of the tide, and lie at anchor secure from all winds, except the northerly or north-easterly.

Mr. John Smeaton, in the year 1767, who was consulted upon the best means of improving it, found that the mouth of the river being open to northerly winds, the vessels could not lie secure without going beyond the elbow of the quay, where there was but very shallow water, and the breadth was much contracted. At a full sea, the mouth of the harbour being wide admitted the waters with so much impetuosity, that they found their way round the elbow and disturbed the quiet of the vessels which took shelter there. To enlarge the harbour, and to increase its security, he advised the construction of a north pier to defend the mouth, and which was to be based upon a natural ledge of rocks.

The entrance to the harbour was at right angles with the direction into and out of the bay; and at spring tides there was 20 feet of water; and between the pier heads, there was several feet at low water, at the lowest ebbs; and at neap tides it was calculated there never would be less than 16 or 17 feet in the harbour, which would be capable of receiving vessels of from 300 to 400 tons burthen.

The length of the pier from the elbow and round the head into the flank was to be 240 feet, its mean height 22 feet, and the mean thickness of the two walls 5 feet. The length within, from the elbow to the said flank, was 132 feet, and the mean thickness of the walls 3 feet. The width of the base was 30 feet, and as the casing walls were built with falling in faces, the interior was filled in with rough stones placed by hand, and well packed. The faces of the wall and parapets only were built in regular courses of freestone, which were laid in mortar, hammer-jointed and faced.

Dunbar Harbour, though situated advantageously at the bottom of a bay, was with difficulty to be entered, as the passage for vessels was extremely narrow; and the sloping of the rocks on the starboard or north-west side, going in, contributed to increase the evil, for vessels being obliged to keep close to the pier were often driven on it by the recoil of the sea from the rocks. John Smeaton, in 1772, to remedy this inconvenience, recommended that the rocks should be sloped off, level with the bottom of the rest of the pas-

sage, and the face built up above high-water mark; by which the passage to the harbour would be widened to 5 yards, and in the narrowest part from 45 to 60 feet. The sea would also be prevented by this means from breaking upon the sloping rocks, and the new pier being carried up sufficiently above high water mark, by means of rope, vessels might be towed when they did not come in with sufficient fresh way to keep them clear of the entry.

He also advised that a pier should be carried out upon the ledge of rocks which at low water were dry, on the south-east side of the entry from the north angle of the present pier to the Beacon rock, which would defend the passage from the surge of the sea, and serve as a help, by its projection, to the throwing a rope on board a ship on the larboard side. As the construction of a pier that would resist the full stroke of the sea ought to be of great strength, and consequently its expense might be objected to, he devised a gangway, to extend as far as the Beacon rock, where men could give the necessary assistance by heaving a rope on board, which might be executed at a moderate cost.

This structure was proposed to be composed of few materials, for it was found that it was generally better to elude the force of the sea than to resist it, and the less matter opposed to its action the better, provided that be securely and permanently fixed. The rocks were to be bored by a jumper, 1¼ inch diameter; to these the eye-bolts were to be forged, a little tapering, and larger than the holes, so that they might be driven tight, by means of an iron maul; and if they were found too small, strips of iron plate were to be introduced, and in a short time the rust would prevent their being moved or drawn out.

As this proposed pier would receive the full stroke of the sea, when the wind was south-easterly, it was not only necessary that it should be built very firmly, but in such a manner that the ordinary seas should not break over it; he therefore proposed that it should be raised 9 feet above high water at spring tides, which is 22 feet above the low water line at the pier head, and that it should have an inclination, as it continued from the south-west towards the land. Such a height would carry it considerably above the rocks, where it was built, and therefore, instead of so large a quantity of backings as would be necessary to make the whole good to that level with the land, he proposed it to be built upon the other side.

The rocks at the foot of the pier were to be removed before the pier was built, and where the pier was founded, the rocks were to be cut off level, so that the lower course of stone had a proper bearing.

Dunbar had its harbour originally at Belhaven, some distance from the town, though within its liberties.

Cromwell began the eastern pier of the present harbour, and some years afterwards the latter was deepened by taking away, over its whole surface, 8 feet of the solid rock. After this work of great labour and expense, a new pier was built. Between the harbour and the fortress are some basaltic rocks which dip towards the south, and are crystallised into either triangles or hexagonal figures like those at the Giant's Causeway.

Leith, the port of Edinburgh, stands at the mouth of a small river of that name; the harbour at neap tides has about 8 feet water, and at high spring tides nearly 16 feet. There is a communication with Edinburgh by a causeway nearly two miles in length, and 50 feet in breadth. In 1777 great improvements were made in the harbour; the pier was continued to a considerable distance into the sea; a quay, basin, and docks, were at the same time constructed at a great expense; and, in 1801, Mr. Rennie commenced a new dock, since which others have been suggested and partly carried out, and to raise the vessels there are slips with iron ways; the ship is supported by a cradle which runs upon wheels.

Adjoining to Edinburgh, on the north, is the Frith of Forth, or ancient Bodotria, which is from five to seven miles in breadth; the largest of its bays is that of Musselburgh, which advances several miles to the south of the village, whilst the harbour of Leith occupies the angle or peninsula formed by the line of the Frith of Forth on the north, and the Bay of Musselburgh on the east.

The trade of Leith is considerable, and one of the docks for building ships formed at the entrance of the new basin presents three quadruple rows of steps, 29 inches high, and 11 inches in breadth, which gives a total depth of 21 feet. The division of the rows is marked by a bench 20 inches in breadth. The breadth of the dock at bottom is 44 feet, and the entrance to it is about 35 feet; the entire breadth at the top or level of the ground is 70 feet.

An iron bridge, 12 feet 6 inches in width, composed of 6 ribs, and which cost 1365*l.*, is placed over the entrance to the basin.

On the south side of the Forth, at Newhaven, is the chain pier constructed by Captain Brown.

Leith is protected by a fort, which was considerably strengthened by Cromwell; since whose time a battery has been constructed on an eminence behind the docks, which extends to Newhaven; this is surrounded by an intrenchment, and defended by bastions. In the

year 1485, a law was passed, prohibiting the inhabitants of Leith from engaging in any commercial intercourse with the people of Edinburgh, and also forbidding the latter to admit the former into partnership, on pain of forfeiting the privileges of the city, so great was the jealousy between the two rivals for commercial advantages; and it was not till the

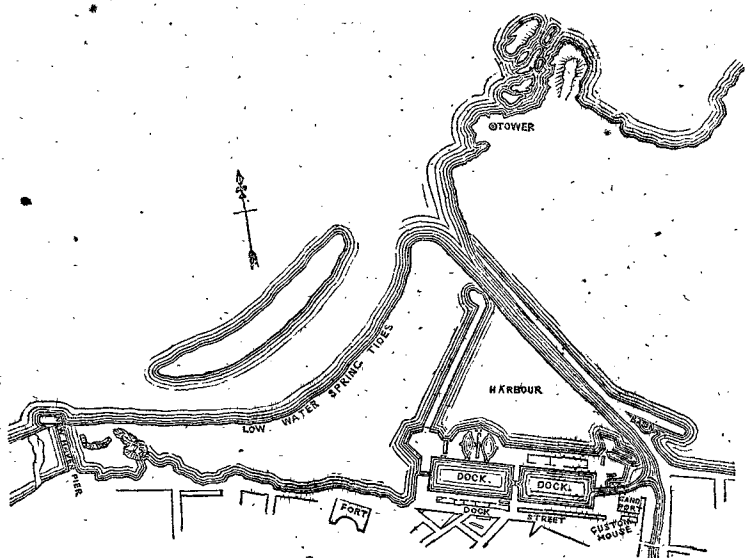


Fig. 334. LEITH HARBOUR.

citizens of Edinburgh purchased the surrounding land of the feudal lord that any thing like unity or harmony was established, and their common interests found to be identical.

Dundee Harbour is entirely formed by art, and by considerable difficulty it has been made to answer the purpose of sheltering vessels, and render them safe and quiet; but the

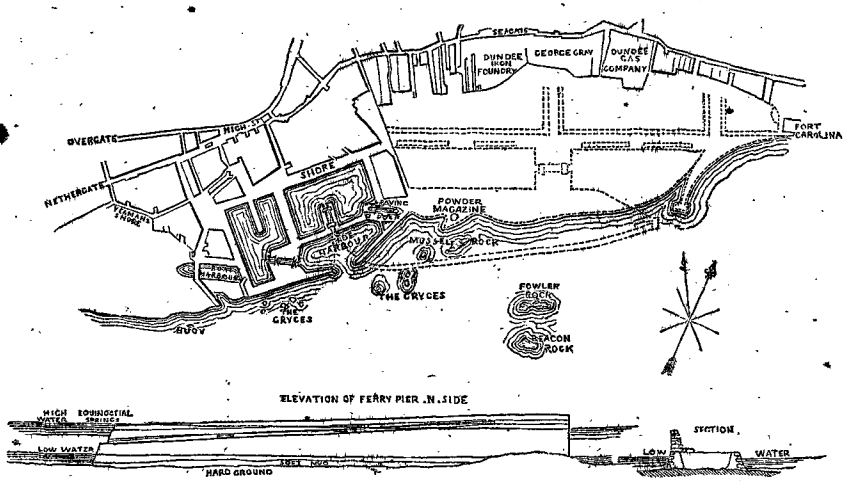


Fig. 335. DUNDEE HARBOUR.

means adopted to make the entrance convenient and easy of access has rendered it more liable to the deposit of mud and sand; the method formerly employed to cleanse the harbour from the silt was by allowing a quantity of water to pass through sluices from the basin, and at the same time causing a number of men to throw into the current the

mud, that it might be washed out to the mouth, and afterwards carried away by the tides.

John Smeaton, in the year 1769, finding that during spring-tides, at the tide of ebb a strong current set past the end of the pier, which was diverted from the harbour mouth, suggested that openings should be made, by which the water might pass, for the purpose of clearing away the mud accumulated near the middle of the harbour: he recommended two sets of tunnels to be made, three and three together, 12 feet wide each; these tunnels to be arched over, so as to form a level platform at top, and the passage for the water to be made through the rocks, down to the level of low water mark. He also suggested that the channel should be turned, and that the small pier already constructed should be removed, and the rock levelled, that the water in its passage from the tunnels should meet with no impediment; and then the tidal water would pass with more force, and act more efficiently in scouring away the deposits.

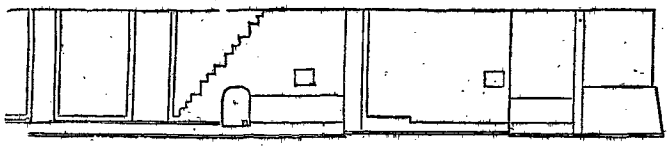


Fig. 336. SECTION OF SLIP LONGITUDINALLY.

Thus, by means of strong currents, and the aid of men, as before, it was calculated that the harbour might be kept tolerably clean; and he advised that the sluices should be made larger, as well as the basin; and that the water should not be let off in small quantities, as that was not making the best use of it, for a quantity of water, when a certain power was given, would move that very expeditiously, which, applied in a less degree, suffered the matter to remain.

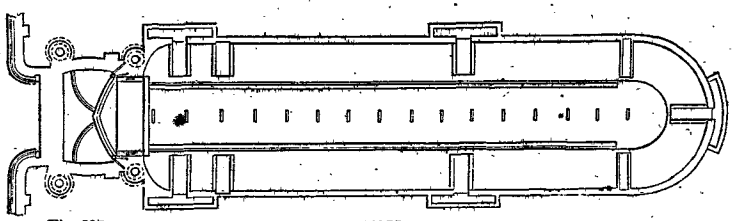


Fig. 337. SLIP AT DUNDEE.

The water in the basin, discharged at once in a body, would remove obstacles, which would remain, if the capacities of the openings were only such as to allow the waters to be a quarter of an hour running out.

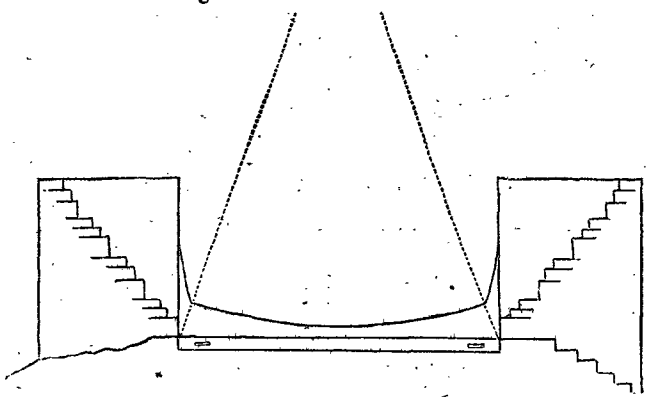


Fig. 338. SECTION OF SLIP TRANSVERSELY.

Smeaton recommended that the sluices should be made quite water-tight, and that the doors should not be cut, so as to form a valve to let in the water, but that one door should

be opened at a time by hand, for this purpose; and to prevent any accident he suggested that a small tunnel with a valve should be used, in part to let in, and effectually to keep in the water. Without the use of men, it was imagined the harbour might by this means be kept clean; and occasionally they might be employed to remove what the sluices could not effectually do.

This harbour, which is on the left bank of the Tay, is often greatly inconvenienced by the quantities of sand deposited within it. When the tide ebbs, it is brought down the river, and when it flows it is brought from what has previously been carried out to sea. Mr. Telford, in 1815, repaired and extended the quay, and constructed a new dock, 250 yards long, and 150 yards broad.

An act of parliament was obtained in the year 1815, for the improvement of this harbour, and the management vested in commissioners. Mr. Telford was employed to carry on the several works, and a floating dock, 750 feet in length, and 450 feet in breadth, with an entrance lock, 210 feet long between the gates, and 55 feet in width, has been constructed, as well as a graving-dock, the floor of which is in length 265 feet, and breadth at bottom 40 feet, and at top 68 feet.

On the site of the entrance lock, at ordinary spring tides, is a depth of water of 19 feet, and at neaps, of 14 feet. And the total cost of these works was 119,835*l*.

The ferries at Dundee required proper landing-places. One was formed on the north, nearly 150 yards in length, which has a parapet and raised footpath, as well as an inclined slip for carriages and cattle, 30 feet in width; it is supported on arches, so that the flux and reflux of the tide is not prevented from scouring the back of the protecting pier of the western harbour.

On the south side are two connected slips with a protecting wall between them, so that there is shelter provided against all winds; and in every state of the tide, embarkation may go on, and boats be under shelter.

The cost of these slips and approaches was 24,600*l*.

Bell Rock Lighthouse is situated in west longitude 2° 22′, and north longitude 56° 29′, eleven miles south-west from the Redhead in Forfarshire. The rock on which it stands is a red sandstone, of a fine grain, and containing minute specks of mica; the surface is very rugged, and full of cavities, owing to the fracture and overlapping of the strata. It consists of an upper and lower level, being highest at the north-east end, which is partially left by the tide at low water of neaps, whilst the lower level is only seen at spring tides; at which time its dimensions are about 427 feet in length, and 230 feet in breadth.

The ordinary rise of spring tides is about 15 feet, and of neap tides 9 feet; but the state of the weather varies this materially. The course of the flood tide in moderate weather is south-west, and of the ebb tide north-east; and the spring tides have a velocity of about 3 miles an hour near the rock; and neap tides about 1½ miles.

This celebrated rock is 11 miles from the nearest land, and is the obstacle to the navigation of the firths of Forth and Tay; it is also dangerous to all vessels trafficking the North Sea and German Ocean. In the year 1806 an act of parliament was passed to construct upon it a lighthouse, and Mr. Robert Stevenson was appointed engineer to carry the same into effect. The design approved of by the commissioners was one on the same principle as the celebrated Eddystone.

A work-yard was established at Arbroath, and a quantity of granite was procured from Aberdeen for the outside casing, and sandstone from Dundee; these materials being prepared, and implements for lifting heavy blocks being provided, the works were begun on the rock on the 17th of August, 1807. The workmen commenced by boring a number of holes, to receive the lower ends of six large beams and six smaller ones, which were to support a wooden beacon, or temporary residence for the workmen during the summer months. Pieces of Memel timber 50 feet in length were placed round a circle 36 feet in diameter, and met together at the top, on which was constructed a wooden house, which consisted of three floors. The lower one was store-house and kitchen; the second, in which the beams crossed, was made into two cabins: one was occupied by the engineer, the other by his foreman; the upper room was fitted up with three rows of beds for thirty workmen.

Below these three apartments, at a height of 25 feet from the rock, was a temporary floor, on which the mortar was prepared, and a smith's forge for sharpening the picks and workmen's tools was fixed. The violence of the sea at times, however, was sufficient to lift this floor, and send all that rested upon it adrift: yet during the five years that operations were carried on, this beacon, which was immersed every tide from 8 to 12 feet in water, was found of the greatest utility.

During the first part of the work, it was necessary at every tide to go to and fro in row boats, each of which contained sixteen persons. In the winter months, the workmen were employed on shore preparing the various stones, which, after being carefully fitted together, were all numbered and marked as they were to be placed in the building; and

this was highly necessary, as the several courses were dovetailed together, so as to form one mass, from the centre to the circumference. The stones were all bored for trenails of oak and joggles of stone, in the same way as practised at the Eddystone.

The lighthouse is 42 feet in diameter at the base, and 13 feet at the top. The part constructed in masonry is 100 feet in height, and including the light room it is 115 feet; the mortar used was sand, pulverised lime, and puzzolana, in equal quantities. The ascent from the rock to the top of the solid part, or lowest 30 feet, is by a trap ladder; and from the entrance doorway a circular staircase leads to the first apartment, which contains the fuel, water, and stores. The other apartments are approached by wooden stairs; they consist of a light store-room, a kitchen, bed-room, library, and light room; in all, six stories.

The three lower rooms have two windows each, and the upper four, all glazed with thick plate-glass, and guarded on the outside from the violence of the spray of the sea by wooden shutters. The light-room, which is 88 feet above the medium level of the tide, has around it a projecting balcony with an iron railing; the interior dimensions of this octagonal room is 12 feet in diameter, and 15 feet in height. It is framed of cast-iron, and glazed with plate-glass, each plate being 30 by 27 inches; it is terminated with a dome roof, with a circular ball; and the light used is from oil, with Argand burners, placed in the focus of silver plated reflectors, hollowed to the parabolic curve by hammering only. These reflectors measure 24 inches across, and the light is so powerful that it may be seen, when the atmosphere is clear, 6 or 7 leagues.

The above lighthouse is the most important in the northern division; the others, erected on the points or promontories connected with the main land, or upon the islands on the coast of Scotland, including the Isle of Man, are more rudely constructed. That at the Mull of Kintyre in Argyleshire, almost inaccessible by sea, from the rocky and precipitous state of the coast, stands 240 feet above the level of the sea, and so difficult is the approach, that the stores cannot be landed nearer than at a spot six miles distant.

The Pentland Skerries in Orkney consist of two islands surrounded by a reef of sunken rock: one of these is about 15 acres, and has been entirely stripped of its soil by the sea washing over it; the other, called the Great Skerry, contains 75 acres: on both are lighthouses, not, however, remarkable for their construction.

The methods adopted till lately on these coasts for distinguishing one light from another, where the distance and bearing by the compass were not sufficiently marked, was effected by double and single stationary lights, a method expensive and not to be relied on as a guide to the navigator, from the frequency with which they were made to occur on the coast in many districts; the revolving light has been substituted to great advantage, which varies its character by the different tints given to the glass.

These several lighthouses are under the direction of a board of commissioners, except those of the Tay, which come under the management of the Trinity House; the Commissioners of the Northern Lighthouses were established about the year 1780, and six years afterwards a bill was brought before parliament, to enable them to erect several new buildings on the coast, which had become frequented by the vessels engaged in the fisheries.

Arbroath, which stands on the river Brothwick, has a small harbour of a rectangular form, defended from the sea by a wall of hewn stone on the north, and by a pier on the south side. The entrance is closed by a floating boom, which slides between a double row of piles, and is made to ascend by a capstan.

Montrose is situated in a fine bay, and at its quay vessels of 400 tons burthen ride in perfect security, sheltered on the north by the town, and on the south by lofty hills.

The town is situated on the north bank of the South Esk, a torrent which descends with considerable violence from the Grampian Hills, and forms a vast bay, near where it disgorges itself into the sea; over the entrance, which is very narrow, is the bridge leading to Montrose, 244 yards in length; the piers are of timber, and have been considerably injured by the ravages of the worms, of the genus *Oniscus*, particularly on the side towards the sea. An opening is formed in the middle of the bridge, by lifting a portion to admit vessels into the bay.

At the mouth of the river on one side are dangerous rocks, and on the other a shallow bottom of sand, without consistence, extending several miles into the bay, which, by an easterly wind, is blown into the harbour, and again removed by the Esk, as the tide ebbs, driving it outwards.

The North Esk runs parallel with the South Esk, and empties itself a little to the north of Montrose; it is crossed by the stone bridge of Money Kirk, of four arches, built at the cost of 10,000*l.*, after the design of Mr. Stevenson.

Gourdon is a small fishing town, two miles south of Bervie, in the county of Kincardineshire. Bervie, the ancient port on the river of that name, has an elegant bridge, on the abutments of which is built the town hall. King David, in 1342, made it a royal town or borough, in consequence of the reception given him by the inhabitants after a violent storm.

A pier, 350 feet in length, was constructed here under Mr. Telford's direction, on one side of the harbour, which is defended by the west rock on the opposite side. Nature has

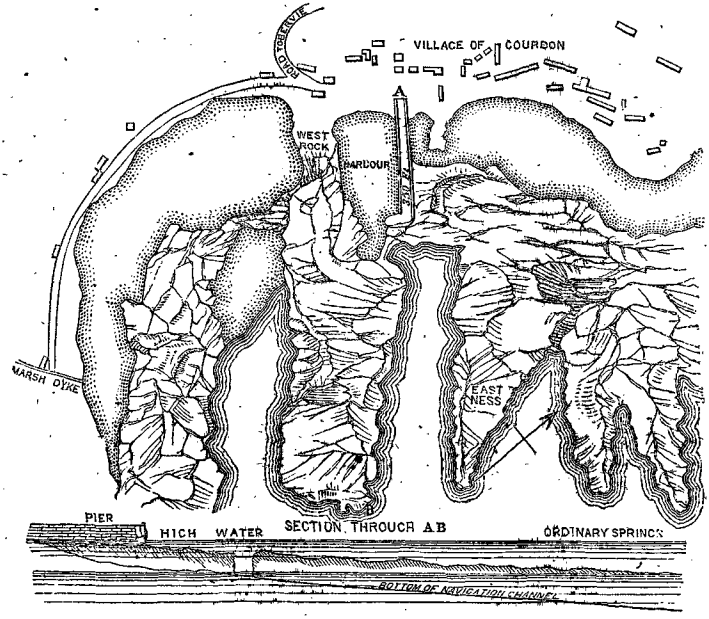


Fig. 339. GOURDON HARBOUR.

done much in scooping out many natural bays on this coast, some of which have deep water.

Stonehaven, 15 miles from Aberdeen, has a secure harbour or a natural formed basin, sheltered on the south-east by a high rock, which runs into the sea, and on the north-east by a quay.

Aberdeen Harbour, which is 106 miles from Edinburgh, was extremely difficult to enter, in consequence of a bar formed just outside the mouth of the Dee, composed of a shifting bed of sand, gravel, and shingle, deposited on the north side of the entry; this, with a north-easterly wind, was driven into the main channel, and choked it up; the quantity driven depended upon the state of the tides, the land speats, and floods or freshes of the river, which here falls into the sea.

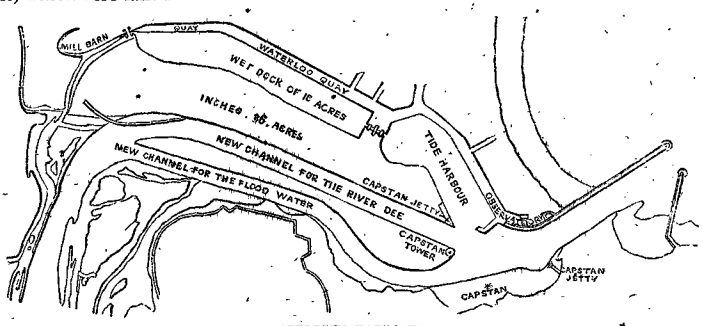


Fig. 340. ABERDEEN HARBOUR.

When Mr. John Smeaton, in the year 1769, sounded at the mouth of the harbour, he found 4 feet upon the bar at low water; on the sixth day after new moon, and at high

water. full 14 feet; but at ordinary spring tides there was the same depth upon the bar at high water, and at low water it was left with only the run of the river over it. The neap tides usually made 10 feet water upon the bar. Outside this bar the water gradually deepened, and ships rode conveniently at low water, protected from all winds, except the north-easterly and easterly, which blew into the harbour's mouth.

The bar, according to Smeaton, was thus formed; the whole coast, which stretches away northerly, is for miles a flat and sandy shore, and the north-east wind acting obliquely upon it brings the sand and gravel intermixed coastwise towards the south; and as the coast, from the south side of the entry, stretches away nearly east for ¾ mile, these sands would be deposited in the angle of the coast formed at the harbour's mouth, if the waters of the Dee did not force its way through them, which they do, and maintain more or less an open channel; a hard gale of wind at north-east, bringing the sand and gravel coastwise southward, puts also in agitation that which has been previously lodged on the bank on the north side of the mouth of the harbour, and at the same time forces it into the entry, and if at that time it happens to be spring tides, and little fresh water in the river, a strong

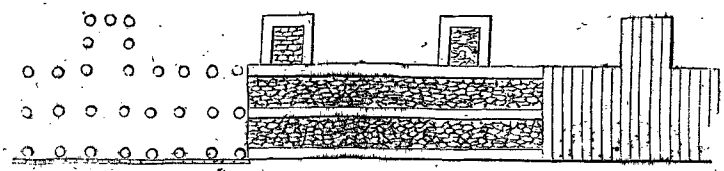


Fig. 341. PLAN OF BEARING AND SHEETING PILES.

tide of flood is the consequence; this, together with the wind, carries the gravel and sand into the channel of the river, and the fresh water being short at the time, the reflux will be languid, and, impeded by the impetus of the sea, and it cannot return.

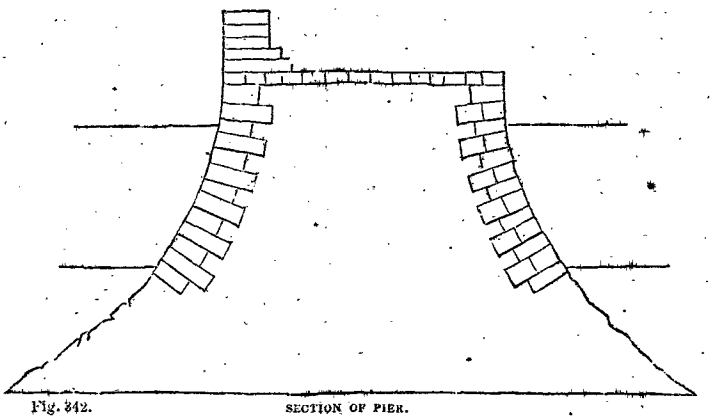


Fig. 342. SECTION OF PIER.

A continuance of land floods, either at spring or neaps, when the wind is moderate from the north-east, scours the sand and gravel away from the mouth of the harbour, and carries

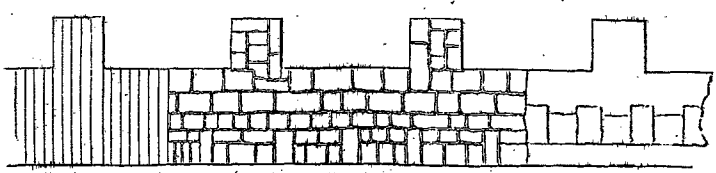


Fig. 343. PLAN OF THE PLATFORM.

it into the roadway, from whence it gets round the point of Girdleness; and if there is with a strong land fresh low spring ebbs, which give the current the greatest fall to sea, and at the same time run bare over the bar, with a moderate wind to the north-east, the stony

body of the bar will be cleared of sand, and the harbour's mouth found in the best state.

To prevent this constant state of fluctuation that the harbour was subject to, Smeaton recommended the erection of the north pier, which not only confined the land freshes till they arrived at deep water, but prevented the sand and gravel from being driven in. The first stretch of this pier carried out was 400 feet; this part not being subject to be overflowed by the tide, the base was 20 feet, the width at top 12 feet, and the height 12 feet.

The second stretch, another 400 feet, with a mean base of 28 feet, 14 feet 6 inches at top, and 20 feet high; the third stretch was 546 feet beyond the last, having at a mean 36 feet base, 24 feet top.

The sides at a medium were 4 feet 6 inches thick, filled in with rough stones.

The pier head was to have had a base of 60 feet diameter, 48 feet at top, and 24 feet high.

The parapet, the whole length of which was 1400 feet, had a base of 4 feet 6 inches, and 3 feet width at top, and was in height 4 feet, and the estimated cost was 10,000*l.*

In the year 1778 Smeaton found the pier completed according to his suggestions, and it had produced the increase of depth and freedom of passage he expected; but the swell at high water, meeting with nothing to control it, made its way through the clear passage between the two piers, where meeting with nothing to break or disperse it in the bay, they turned round along the shore, and spent their fury upon any objects they came in contact with. To remedy this inconvenience, he suggested that at the commencement of the old Sandness Point, a deposit should be made of rough stones, projecting towards the middle of the open space, rising towards the pier, and sloping towards the low water; this was to be of rough granite.

This catch pier he fancied would have the effect of quieting the harbour, and leave a clear water-way of 300 feet of navigable channel, and it was not thought requisite to carry this breakwater higher than spring tide mark, the seas being suffered to break over it at high water.

There is nothing which tends to quash and disperse a wave when it is raised so well as allowing its breaking upon a sloping beach; on this account the continuance of the south piers so far to the westward has an injurious effect, in preventing the seas from spending and breaking, as they would do, upon the naturally sloped shore; and this south pier was required to be removed, as the use of the new catch pier was to throw the seas more effectually over to the south side, and, unless there was a sloping beach for them to break upon, they would again be reflected back from the side towards the north, and produce effects disagreeable to some part of the harbour.

This catch pier was formed of blocks of split granite, which was done at the quarries; they were cut into wedge-like pieces, and made of parallel shapes, and each alternate stone composing the circular end of the pier was a header, and the others tended towards the centre, whilst those lying between were retained in the manner of a dovetail; and the header stones themselves being anchored at their tails, that is, at their inward or smaller ends, to an anchor or cross stone, by means of an iron cramp to each, the whole were held compactly together. It was particularly requisite that the wedge stones should be made to fit properly.

The wedge-like header stones which formed the turn to the head, and which held the intermediate stones between them, were tied to the anchor stones at their tails by iron cramps, an inch square, turned down and rounded at each end, to go into jumper-holes, and fixed in them with wood wedges without lead, as the weight of the courses above them was sufficient to keep them from starting.

This harbour seems to have been viewed by Smeaton as a tide harbour. The River Dee, which admitted the tide to flow upwards about 2 miles, and spread itself over some very flat ground, did not acquire sufficient strength, to carry out all the deposits that were borne down from the country above, through which the river flowed. The tide, meeting the fresh water, occasioned the sand, stones, and mud, to be deposited, and at last a bar was formed, which almost obstructed the entrance for large vessels.

Smeaton finding the river spread over a space upwards of 500 yards in breadth, immediately had recourse to confine it in a narrower channel; and for this purpose it was that he founded the north pier, which continues 700 feet eastward from ordinary high water mark, and then starts off to the north for another 500 feet, in order that the current might have a proper direction given to it.

Another pier was also built on the south side of the river about half the length of the other, and two small jetties and a small basin were formed by Mr. Smeaton, in conformity with the act of parliament obtained in 1773.

In the year 1810, another act for the improvement of this port was obtained, and Mr. Telford employed to carry out its object. He commenced by ascertaining the quality of

the soil by boring, the nature of the land floods and tides, and drew up a report upon the subject; his object being to provide wharfage and floating docks, and new ground for shipbuilding on the mud banks called the Links, to place locks and graving docks capable of admitting vessels on the best foundations, and to provide the means of scouring the docks, and cause the flux and reflux of the tide, as well as the land floods, to act most effectually on the existing bar and prevent future accumulations there, so as to preserve 4 feet additional depth of water, and by this means admit large vessels at neap tides, and form a communication between the Aberdeenshire canal and the new harbour.

The pier on the south side, which was constructed by Smeaton, having been destroyed in 1807, Mr. Telford commenced his works of improvement by erecting another in cut granite, and finished it with a slope of five horizontal to one perpendicular; this was completed in October, 1809.

In the following year the north pier was commenced, and by the aid of a railway its entire extension of 300 feet was completed within the twelvemonth; this was found so beneficial to the harbour, that it was afterwards extended another 865 feet beyond Mr. Smeaton's head, which was performed in three seasons, in the full expanse of the German Ocean.

The outer head having in the following winter received considerable injury, its slope was altered, and made five to one, since which it has stood perfectly well.

The foundations resting on loose sand and gravel, it was found necessary to consolidate the work under low water by dropping from lighters large stones, and filling the interstices up with smaller, until it was brought to within a few feet of low water, at which level the ashlar line commenced. The stones were not laid horizontally, but at an angle of 45°, and in this way was the masonry worked, until it arrived within 18 inches of the top, when it was built level.

By this means the work was more rapidly advanced, and less liable to temporary derangement, for while the ashlar wall was being carried up on both sides, the middle was built, which was performed by a careful backing of large rubble stone to within 18 inches of the top, when the whole was coped with granite, 18 inches in depth, over which, on the north side, was added a cut granite parapet the whole length of the pier. The outsides of the pier are built with roughly dressed granite ashlar, the headers being 3 feet 6 inches in length, and the hearting of large rubble, the interstices being filled up with smaller stones.

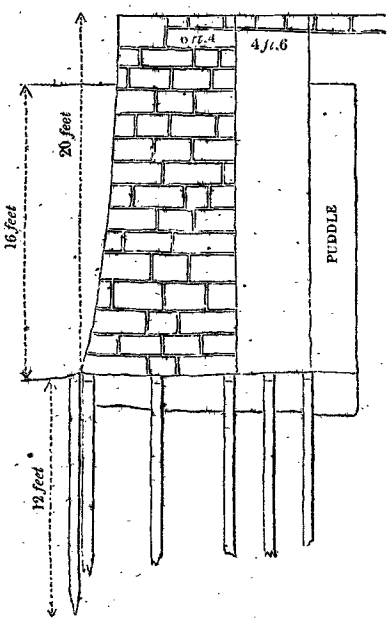


Fig. 344. TRANSVERSE SECTION.

The rocks in the neighbourhood are chiefly a gneiss formation, and as it is difficult to dress this stone into a regular shape, the masons call them heathens; some of these, of large dimensions, weighing from 5 to 30 tons, were slung by the aid of machinery between the bows of two lighters, which had counterweights at the stern, and by this means floated to the pier head, and deposited in the situations allotted them.

A railway laid down along the old pier, with a double crane at the end, movable on rollers, and advanced as the work proceeded, was found of the greatest convenience.

Besides this, six lighters of 40 tons each, with a crane mounted on each, were employed to bring the stone used in the lower part of the work.

The pier on the south side was carried out, to correspond in extension with the other; it was not, however, made parallel with the north pier, but formed a solid breakwater from the south shore, in a north-east direction, with a space at its entrance of 250 feet. Within this breakwater there was a sloping beach, that the surge might spend itself freely, and not agitate the waters within the harbour. The length of the breakwater is 800 feet, and it is constructed of large rubble stones, as they came from the quarry, except the head, which is formed of roughly dressed ashlar, laid to a slope of 45° where exposed most to the sea's action, and about

half that slope on the inside. It is raised 5 or 6 feet above the level of high water at ordinary spring tides, and the top is covered with large blocks of roughly hammered stone. The breakwater is protected by a shoeing of rubble stone; by narrowing the entrance, it materially deepens the channel; a permanent depth of 5 or 6 feet water has been obtained.

By means of a dredging machine, worked by a steam-engine, the interior of the harbour was deepened; an additional 3 or 4 feet of water has been obtained, throughout the whole extent, for more than a mile in length, so that vessels of any description arrive at the quays, and there is no necessity for lighters.

In the year 1815, 900 feet in length of the new wharfs and the capstan towers were built, as well as the embankment formed, on the south side of the wet dock; the works remained in this state till 1830, when 1350 feet of new wharf was built, and the embankment of the wet dock was proceeded with, as well as other portions of the work.

The whole breadth of the new wharf is 100 feet, and its foundations are laid on a platform of timber, resting on piles, with a row of sheet piling in front; the outside face of the other wharfs is built with granite ashlar, backed with hammer-dressed masonry, laid in lime mortar, and the outside joints pointed with Parker's cement.

The general bottom of the harbour is sand and gravel, so that it was necessary to have coffer-dams, for the purpose of constructing the foundations for the various buildings erected, and chain pumps were used.

The right bank of the new channel was completed in 1832, its length being 1630 feet, and that of the spill or water bank, 4107 feet.

The cost of these works was as follows: —

	£
Extending the piers and breakwater	81,955
Dredging the inner harbour	17,999
Constructing new wharfs and common sewer	39,738
Forming a new channel for the river, including the capstan, towers, and jetty, also constructing bulwark and embankment	15,398
Making a communication bridge to the Inches	5,500
	£160,590

Since these works were performed, a new channel for the Dee has been opened, and a spill water channel formed, by which means the river is kept entirely out of the harbour. A cast-iron turn bridge has been constructed across that part of the harbour called the Inches, which, by means of an embankment, has been considerably enlarged. A wall has been built, 3200 feet in length, forming a spacious quay, 100 feet in breadth, and paved throughout; this is in addition to the 920 feet length previously built. A quay wall 1200 feet in length has been also built on the Inches.

There is now altogether 6290 feet of quay berthage to this harbour, and a building slip, of a size sufficient to receive the largest steamers, has been built according to a patent obtained by Mr. Morton.

Mr. Morton's mechanical slip was patented in the year 1818, and it has been put down at most of the ship-building ports in the kingdom; the patentee, in giving his evidence before a Select Committee appointed to inquire into its merits, enumerates about forty slips built a few years after its invention.

The chief feature is that of placing a complete wheel carriage underneath the bottom of the vessel, which carriage has a long straight beam extending beneath the whole length of the keel, with blocks fitted upon it for the vessel's keel to rest upon. As all vessels are straight at the underside of the keel, or have some determined curvature, it is easy to dress the blocks, which are placed on the middle beam of the carriage, to either a straight or curved line, before the ship is taken up; and the slip is so constructed, that the form of the carriage undergoes no alteration when the weight of the ship is placed upon it; and the carriage is substantially borne by three parallel lines of iron railway, founded upon either timber and piles or masonry, upon which it traverses upon numerous wheels or trucks of cast-iron.

The ship, when placed upon the carriage, is kept in its perpendicular position by cross bearers, on which is adapted other timbers fitted to the curvature of its sides, forming a cradle; it is then, by means of tackle, drawn up an inclined plane, by men working at a capstan, or at winches with cog-wheels, the chain being attached to the carriage, and exerting no strain on the ship.

Between the railways is laid a cast-iron rack having serrated teeth, into which strong palls catch, and which prevent the carriage from running down the inclined plane, in case the tackle gives way.

Previously to this system being adopted, it usually cost 170*l.* to haul up a ship of

500 tons, and by Mr. Morton's principle this was reduced to 3*l.*, without any risk whatever.

A durable and substantial slip may be constructed, under ordinary circumstances, at the tenth part of the expense of a dry dock; and the apparatus employed may be moved from one place to another. The vessel may be hauled up at the rate of 2½ feet per minute, by 6 men to every 100 tons, so that the expense of taking up and launching a vessel of 500 tons does not exceed 60*s.*

Peterhead, is situated on the most easterly point of Scotland. The town is built upon the edge of an extensive bay, which affords to the vessels frequenting this coast a very

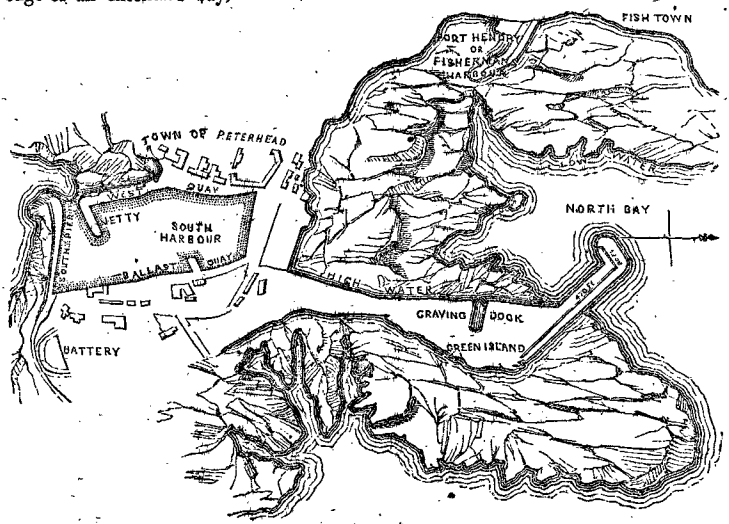


Fig 345. PETERHEAD HARBOUR.

secure anchorage. Besides the old south harbour with its south pier, west jetty, and ballast quay, there is a new harbour formed to the north, with a capacious graving-dock, excavated out of Green Island. The north jetty is carried out 470 feet, and its interior wall was constructed on caissoons, as was the jetty-head which bears to the west, in length 80 feet. This portion in 1819 was partly destroyed by the violence of the sea, and has since been reconstructed upon a broader and firmer foundation.

Peterhead, so famous for its sea bathing, had its harbour considerably deepened by Smeaton, who recommended blasting 30,000 cubic yards of rock; but this operation has not been attended with the success that was expected: wooden boxes or cases were made use of by the workmen employed for this purpose; these movable cofferdams had occasionally the water pumped out of them, and enabled the operation to be carried on at all times without difficulty.

There is 18 feet water at the entrance at the top of an ordinary spring tide, but only 14 feet at the eastern extremity of the pier.

The granite found here, called by the people who work it Pacey Whin, is the best material for building that can be obtained; it is scattered over the whole face of the country in large irregular lumps, and is so hard that it resists the finest tempered edge tool; but is admirably split into blocks of any size required, by the masons accustomed to the work, who are perfectly aware that they cannot split the stone in any other direction than that of its natural "greet," which they ascertain with great facility, and with such certainty, as seldom to be mistaken. After it is split they draw a straight line in the direction of the "greet," and then sink a row of holes along it with a weighty hammer, having blunt points at both ends, and highly tempered; with this pick they unite the holes and form grooves, into which they place a wedge made of the best steel, with a point cut over square, so as to leave a triangular cavity below it; they then strike the wedges in succession with a heavy hammer along the whole line, till the stone splits asunder; the fissure going through to the bottom of the stone, in the direction of the line first marked out, cleaving it into two parts, nearly as straight, though not so smooth, as if cut with a saw. When the stone is cut into a number of slabs, they are split into lengths at right

angles with the former cutting; they are picked over their surface, and smoothed by a tool in shape of a small hatchet, with much labour, and at a cost of 6*d.* per superficial foot.

Frazerburgh harbour lies at the foot of Mount Kennaird, and is 50 miles from Burghhead. The jetty has three bends; the first is in length 272 feet, the second 440 feet, and the end, which returns at nearly right angles, 100 feet.

The thickness of the pier at top is 33 feet 7 inches without the parapet wall, which is 4 feet 6 inches in addition; towards the sea the height is 20 feet 6 inches above low water, and batters considerably; towards the harbour the face is curved.

This harbour, lately so much improved, is now one of the best on the eastern coast.

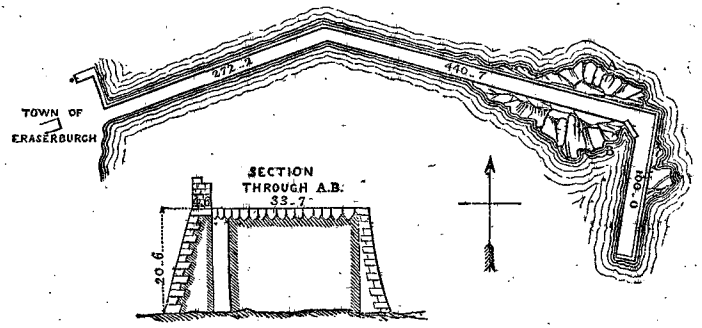


Fig. 346. FRAZERBURGH.

Burghhead, in the county of Moray, has a small harbour well sheltered by a rocky promontory from the north. The trustees, who have the management, expended upon this

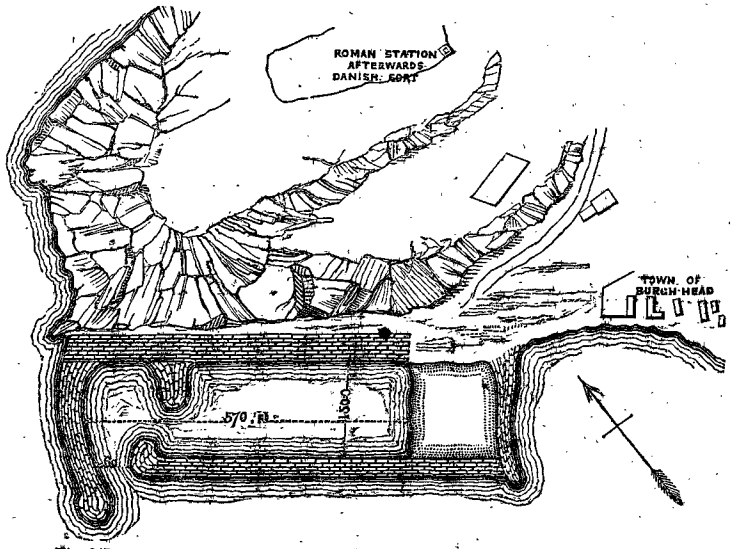


Fig. 347. BURGHHEAD.

rectangular dock 6000*l.*, and the commissioners 2000*l.*; but the whole is dry at ebb tide.

Findhorn is another port on the coast, the bay of which contains upwards of 1000 acres of stiff clay, which is only covered by the flux of the tide, as a bar of sand crosses the mouth of the river, and prevents all violence of the surge; this sand is constantly moving, and the present harbour is at least ¾ of a mile farther down the firth than it was 150 years ago.

Banff, is situated on the side of a steep declivity at the mouth of the Doveran, which rises in Aberdeenshire. A new harbour has been recently formed here, and at the same

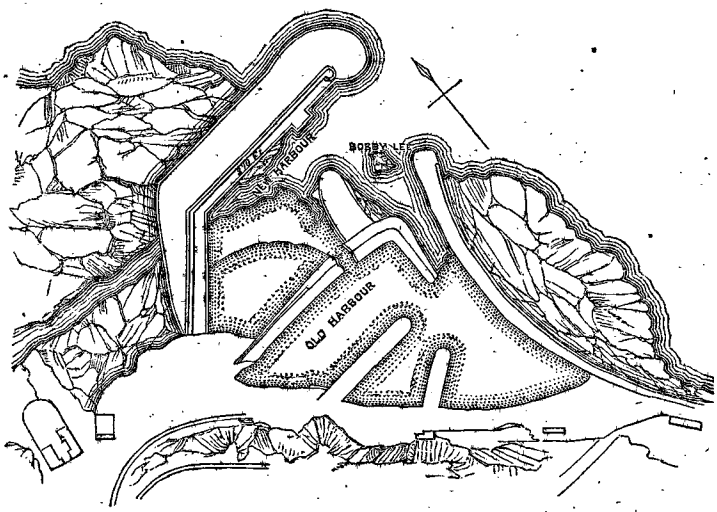


Fig. 348. BANFF.

time that the jetty of Peterhead was thrown down, a portion of this pier, which was laid upon caissoons, was destroyed. The new harbour has a fine quay 370 feet in length, on which was expended upwards of 14,000*l.*, the commissioners for public roads advancing half the amount. The harbour is, notwithstanding the improvements made on it, still inconvenient, from the continual shifting of the sand-banks at the mouth of the river.

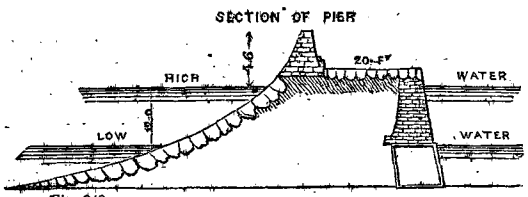


Fig. 349.

The section through the pier shows its dimensions.

Avock, upon the northern shore of the Bay of Inverness, had in 1811 a dry dock constructed; and within the bay are many other small harbours, convenient for fishing vessels.

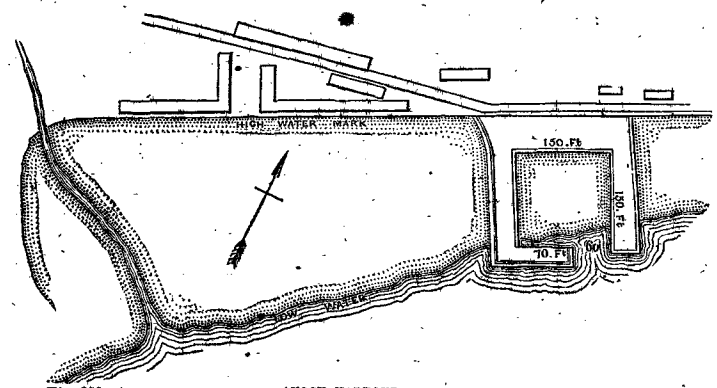


Fig. 350. AVOCK HARBOUR.

Cullen, is another port in Banffshire, to the west of which the river Spey enters the ocean, and forms the north-western boundary to the country. The harbour was by no means convenient until the construction of the jetty, which is 250 feet in length.

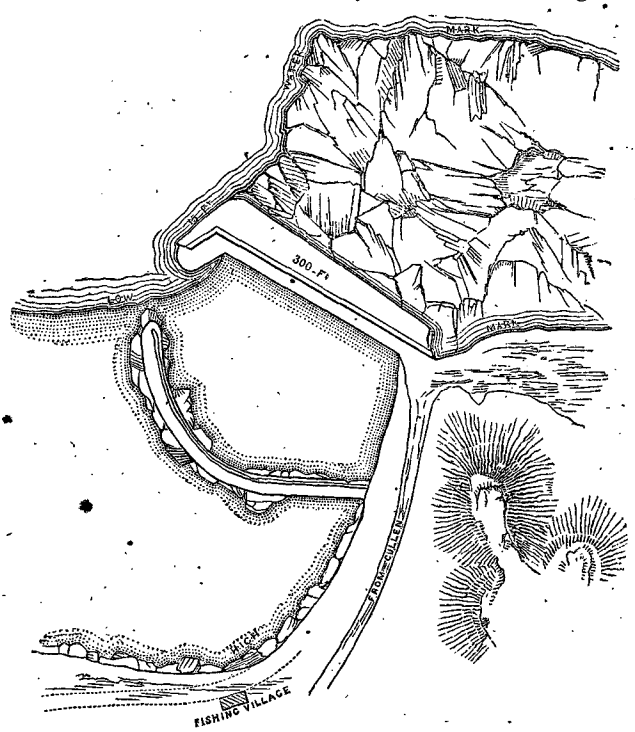


Fig. 351. CULLEN HARBOUR.

Fortrose is at the entrance of the bay, opposite to Fort George, and stands upon the Moray Frith, which, at the south-western point, is exceedingly narrow: after passing the

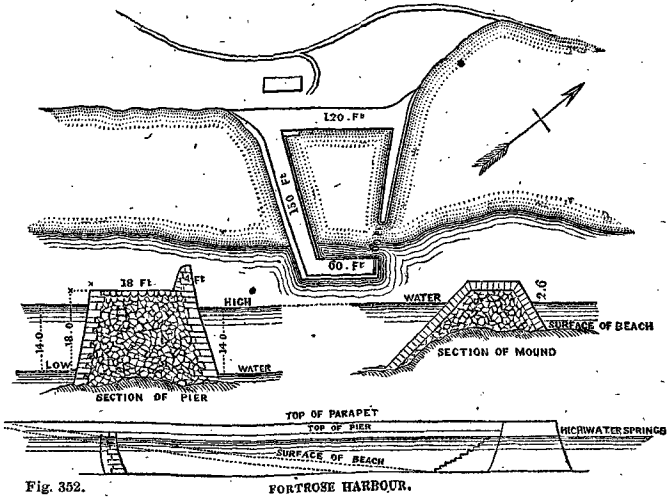


Fig. 352. FORTROSE HARBOUR.

ferry between the two forts it widens considerably. On the side of Fortrose a jetty has been built for the convenience of disembarkation, and a mound has been formed on the other side upon a tongue of land. The pier is raised 18 feet above the level of low water, and is 22 feet thick at top: both sides are faced with squared stone, and filled in with rubble.

Cromarty stands on the inner extremity of the bay, on the banks of the Petter. Two quays have been recently constructed at Dingwall, where vessels drawing 9 feet water may discharge their cargoes.

The Bay of Cromarty has several landing-places, lately built for the convenience of those who frequent this magnificent coast, as Invergordon, Balinghead, &c. &c.

Mahomac, in the Firth of Dornock, which is separated from that of Murray by a prominent tongue of land, has a pier recently constructed for its protection, 450 feet in

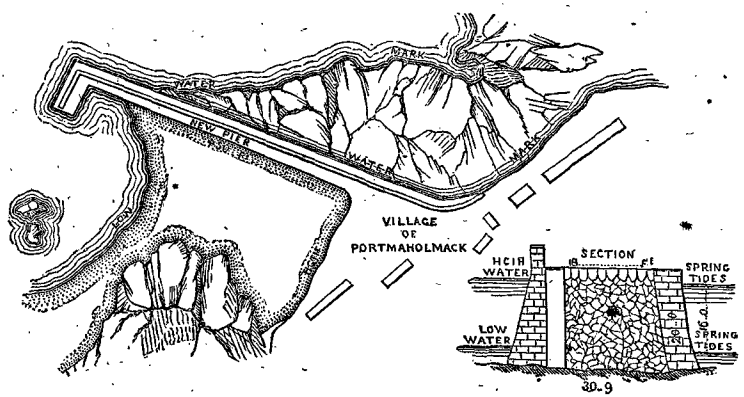


Fig. 353. MAHOMAC.

length, with an end or jetty of 68 feet, returned at right angles. The wall towards the sea batters, and has a parapet for its defence; that towards the harbour is curved on the face, both built of squared stone and filled in with rubble.

Tain is another harbour in this gulf, which is exceedingly narrow.

Wick, in the county of Caithness, has a small harbour protected by a jetty at the mouth of a small river; beyond this resort for fishing boats is seen Cape Duncansby, which terminates the western coast.

Harbour of Pulteney Town. Caithness in Scotland, situated in the latitude of 58° 26′ north, and 3° 5′ west longitude, has been improved by the British Fisheries Society, partly under the late Mr. Telford. A stone bridge connects the improvements with the town of Wick, formed of three arches, having a clear water-way of 156 feet, which was built in 1805.

The rise of the tide at neaps is 5 feet, and at ordinary springs only 9 feet 6 inches; at extraordinary springs, from the lowest ebb to the highest flow, 13 feet.

The north harbour, only adapted for small vessels, being found very insufficient for the growing trade of this improving fishing port, in 1823 the south harbour was undertaken; the quays are built with stone of a hard quality, and vary in length from 3 feet to 20 feet, and 3 feet 8 inches in breadth, and in thickness from 8 to 15 inches. These were set on edge, and the courses placed diagonally in the slope; in the front walls the courses were laid flat, and perfectly horizontal.

The foundations of the slope were formed of stones weighing from 15 to 20 tons each, which were floated to their place by means of casks made of fir; each weighed about 25 cwt., and displaced about 445 cubic feet of water, so that two of these casks would lift 34½ tons of stone.

Four of these casks were made use of, and sometimes they were found useful to lift the vessels loaded with stones; when the water was low in the harbour, they exercised a lift equal to 44 tons, by means of chains passed under the keel. These casks, which did not cost more than 8*l.* each, were found of great service in moving the stone, which cost only 1*s.* 6*d.* per ton, when they were moved three miles, and lowered into their respective situations. When the casks were applied to stones under low water, a wooden frame was made use of for boring holes in the stone, for the insertion of a Lewis of rather a novel form: the shank which was inserted was about 2 inches in diameter at the bottom, and tapered upwards, diminishing to 1¼ inch at the top, where, into the eye, welded at the

top, was inserted the ring, into which was secured the chains. This shank being dropped into the hole prepared to receive it, a wedge was driven in, and by this means secured it most effectually.

After the stones were thus prepared and attached to the casks, at the flow of the tide, they were floated to their destination.

These casks were strutted inside in the manner of the spokes of a wheel, and hooped strongly round on the outside; the stones were attached to them by means of chains, which were passed round each of a pair of casks, the chains being drawn through the eye of the lewis; each stone has inserted in it two lewises, so that it was firmly and securely held by the two casks to which it was suspended. One lewis, even if placed immediately over its centre of gravity, would have been inefficient to prevent the unsteady motion of the stone, and its derangement would have constantly taken place; this ingenious part of the operation was superintended by Mr. James Bremner, in a most masterly manner.

The south harbour was completed in 1830, at a cost of 20,900*l.*

The Orkney Isles, being much frequented by vessels employed in the fisheries, considerable attention has been paid by the Government to some of the ports and landing places during the last few years. These remarkable islands, forming the group known to the ancients by the name of Orcades, are situated between Caithness and Shetland; from the former they are about four miles distant, and from the latter, upwards of twenty leagues; they are separated from one another by sounds, friths, and ferries, some of which are only a mile in breadth, and others more than five; though so connected, the whole are of considerable extent, being seventy miles across from the south-west point to that at the north-east, and forty miles in the other direction. The islands are sixty-seven in number, thirty-nine of which, called Holms, are not inhabited, but afford occasional pasturage for cattle.

Lobsters and crabs are found in great abundance, and the cockle, which, as an article of food, is greatly esteemed. The turbot, sole, flounder, plaice, holibut, ling, whiting, haddock, cod, and numerous other marketable fish, are taken during the season, and forwarded to the different cities and towns of the empire.

The coasts of the whole of these islands, with a few exceptions, may be seen at a distance of ten leagues, where the sea is fifty-two fathoms in depth, which continues within a league of the shore, where it is not less than fifty fathoms. The flood tide comes from the north-west, it is high water at full and new moon about half an hour after nine, the ordinary spring tides rise 8 feet perpendicular, and extraordinary ones 14 feet. At the quadratures the usual neap tides rise $3\frac{1}{2}$ feet, and sometimes 6 feet. The greatest rapidity of the spring tides is nine miles an hour, whilst the neaps have only a fourth of that velocity.

Kirkwall Bay is in one of the Orkney Islands, called the Mainland or Pomona, which forms the centre of the group; its latitude is 58° 33′, and its longitude 0° 25′ west; the town is built upon a neck of land, washed on one side by the bay, and on the other by the sea, which flows at the backs of the houses at high water. This ancient town was formerly

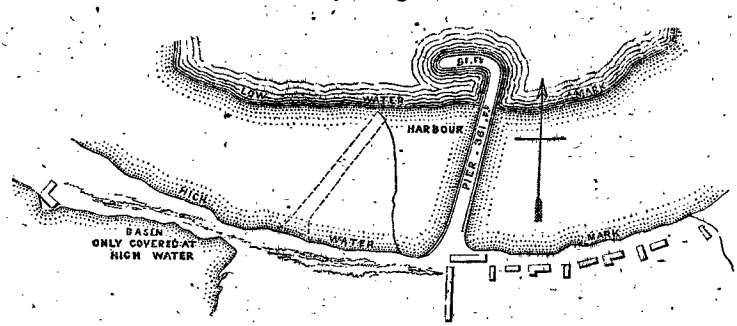


Fig. 354. KIRKWALL BAY.

a place of great resort, and contributed with the boroughs of Wick, Dornock, Tain, and Dingwall, to choose a burgess to represent them in parliament. The harbour is broad, safe, and capacious, with a bottom of clay so firm, and a depth of water so convenient, that vessels of considerable tonnage take anchorage here.

The new pier extends beyond ordinary low water, and returns at the head 91 feet.

Kyle, in the Isle of Sky, is situated on the shore of the narrow channel which divides it from Inverness; this island, the largest of the Hebrides, lies at a distance of about 18 miles south-west from Harris: on the south-east it approaches near to Glenelg, on the coast of Scotland. The length of the island is between 50 and 60 miles, and its breadth 40 miles.

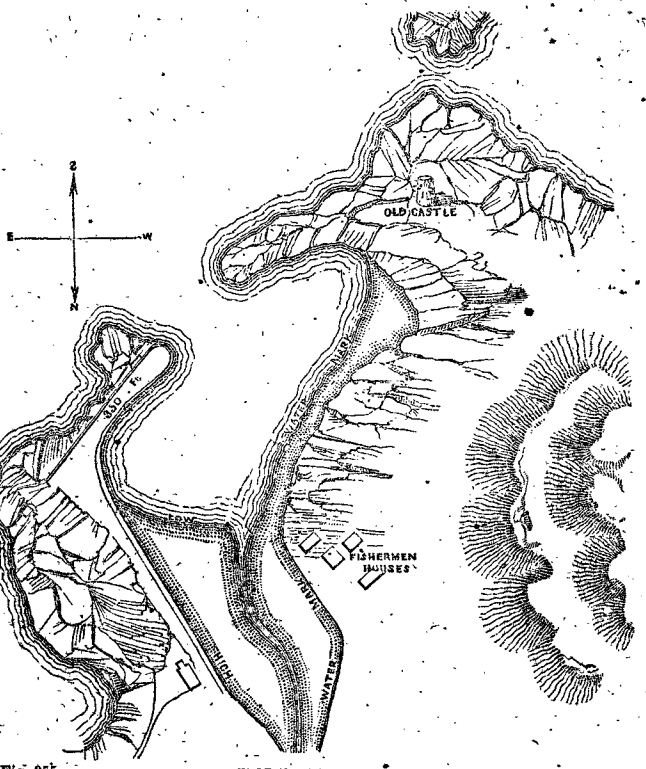


Fig. 355. KYLE HARBOUR.

At the village of Portree or Rhea is a newly constructed landing quay; the country around is mountainous, and some of the highest land is covered with snow at midsummer

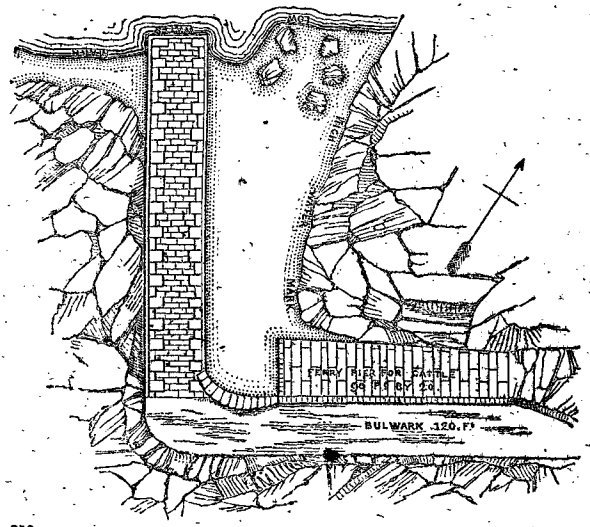


Fig. 356. RHEA FERRY.

There are many fertile plains, and rivers abounding with fish, and sometimes the *Mytilus margaritifera* found here contains pearls of considerable value.

Tobermory, in the Isle of Mull, is a considerable port, with a pier continuing eastwards for 300 feet, or a little beyond low water mark. The British Society for the Encouragement

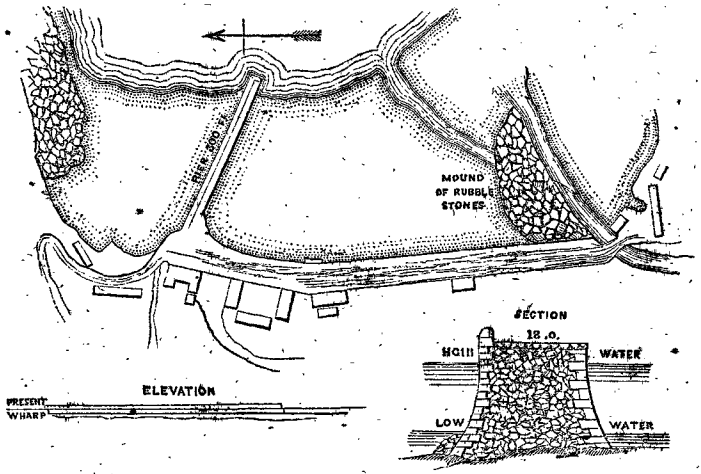


Fig. 357. TOBERMORY HARBOUR.

of the Fisheries have an establishment here; the bay is well sheltered from the ocean by the small Isle of Calve, and it is situated in the track of the shipping which pass from the south northwards.

Tarbet is situated on a small isthmus in the sound of Islay; the strait or sound of Jura is a large and deep gulf, extending along the western coast of a tongue of land, 60 miles in length, which the canal of Crenan divides from the county of Argyle; this canal

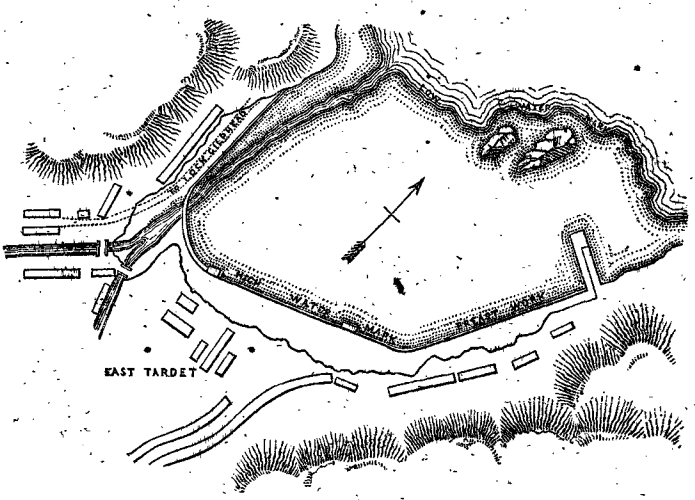


Fig. 358. EAST TARBET.

9 miles in length, enables vessels to avoid a very dangerous navigation; the coasting vessels pass through the peninsula of Cantyre to the extremity of Loch Fine, and then by the canal of Crenan.

Jura Small Isles pier, situated between the ferries of Lagg and Feoline, and constructed under the direction of his Majesty's commissioners, is extremely well executed, and can be approached at all times; the double bend given to it secures the safety of passengers landing at all times. The width at top is 16 feet, and the two faces are carried up with squared stone.

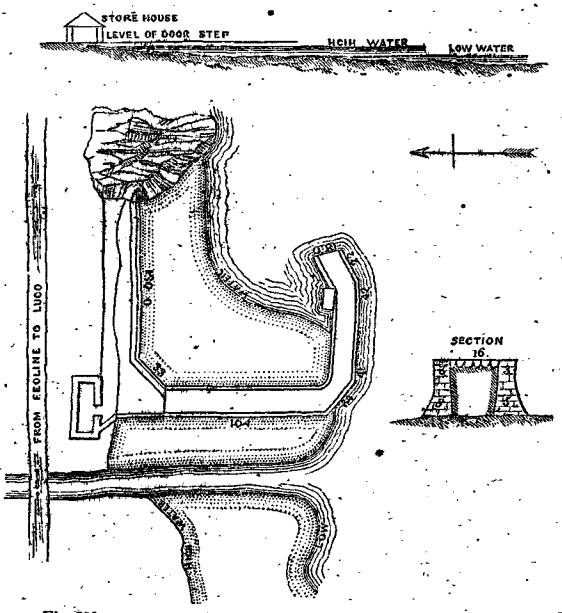


Fig. 359. SMALL ISLES PIER.

There are two very fine harbours on the east side of the island, that to the south, where the above pier is situated, and another to the north, called Lewlandman's Bay: they are within a few miles of each other; the island of Jura, 30 miles in length, and 7 miles in breadth upon an average, is the most rugged of the western group, being composed of rocks piled one on the other, in most admired disorder: Mr. Pennant, who ascended Bienn-an-Oir, with considerable difficulty, describes the grandeur of the prospect from the summit. Sir Joseph Banks found the height of Bienn Sheunta to be 2359 feet above the level of the sea, and Bienn-an-Oir, 2420 feet. The stones forming these mountains are white and red granite, and the shores are covered with a fine sand, great quantities of which are annually carried away in vessels employed for the purpose, to be used in the manufacture of glass. In this island are several cairns, rude obelisks, and duns; the climate, like that of the other western isles, is extremely moist: the winds blowing from the west are loaded with vapour, drawn from the broad surface of the Atlantic ocean, and when they are intercepted by the high lands, the rain often descends in torrents; but although the climate is apparently so unfavourable, there are instances of great longevity among the inhabitants. Gillour Mac Craen is said to have kept 180 Christmasses in his own house; he died in the reign of Charles I.

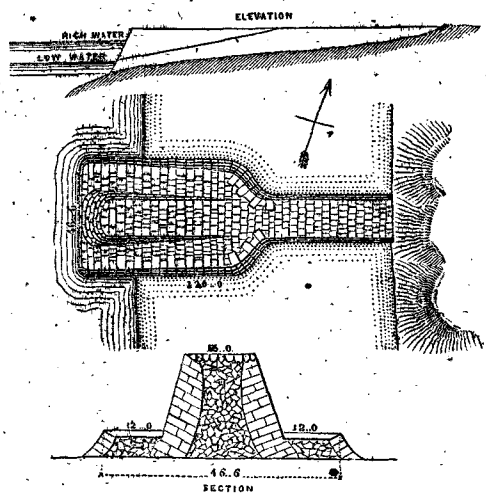


Fig. 360. FEOLINE.

At Feoline we have an admirable specimen of a stone landing-place for all states of the tide. Upon a base of not more than 50 feet are two inclined planes, with a jetty dividing them, intended to be used at high water, and to protect those landing from boats at either high or low water; when the wind blows from the south, the lofty jetty screens the north landing-place, and so with that on the other side when the wind is in the contrary direction.

Corran Ferry incloses a basin for the vessels to receive their freight, and is most admirably adapted for the convenience of shipping cattle; the whole is built of stone, and the walk around is of a sufficient width to be serviceable at all times.

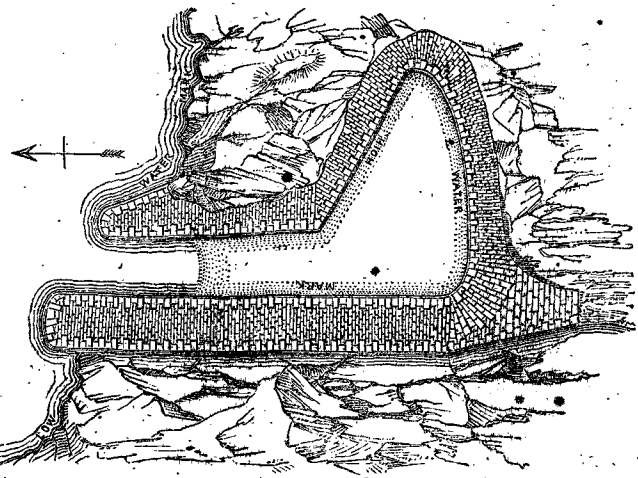


Fig. 361. CORRAN FERRY.

Port Glasgow is 20 miles from the city, on the Clyde, and is built around a basin, which was the first excavated in Scotland: its form is that of a rectangle, but it is not inclosed by lock gates. Beyond this dock is a wide quay, extending along the Clyde for a considerable distance.

The river Clyde has been improved greatly since the period when the inhabitants of Dumbarton, Renfrew, and Glasgow, undertook jointly to remove the deposits in the river by statute labour. Smeaton, in 1755 and 1758, directed his attention to the clearing away of the numerous obstructions in its navigation, and afterwards an act of parliament was obtained for the construction of locks, which was never carried into effect.

In 1769 the river was sounded by Mr. J. Watt; and Mr. J. Goulbourne, of Chester, commenced his improvements by inclosing the river between two artificial embankments, when water was obtained of sufficient depth for vessels drawing 7 feet to reach Glasgow. To contract the bed of the river, walls of stone were built, in a direction at right angles with the stream, at some distance from each other; these were united by dikes, which were thrown up to make the bed of the river one uniform width throughout.

The government of the river Clyde is placed by act of Parliament under the magistrates and council of the city; and all the revenue, arising from tonnage, cranеage, and harbour dues, collected at the Broomielaw, are kept distinct from the funds of the corporation, and are laid out in deepening and improving the river and harbour.

In 1808 a company was incorporated for supplying the city of Glasgow and its suburbs with water, and works of some magnitude were soon after established at Cranston Hill, about a mile below the city; filtering beds are attached to the great reservoirs, and by means of powerful steam engines and iron mains, water is delivered throughout the streets and lanes of the city in a pure state.

The first steam boat introduced on a navigable river in Great Britain plied between Glasgow and Greenock in the year 1811; it was the property and contrivance of Mr. Henry Bell, an engineer of this city; the name given to the boat was the Comet, and the distance, twenty-two miles, was performed in three hours and a half, with an engine of three horse power.

Greenock, on the gulf of the Clyde, has an open basin, around which are many yards for ship-building.

Androssan. To defend the harbour from the violence of the sea, a long pier has been constructed upon a ridge of rocks, which may be seen at low water; it forms a salient angle, whose sides extend from the land towards the west, and from the west towards the north; at some distance from the mole stands a lighthouse, to protect vessels from the shoals at the entrance of the harbour.

A wet dock has been constructed within the mole, capable of holding 100 vessels, drawing 16 feet water; a building dock, of stone, has been added.

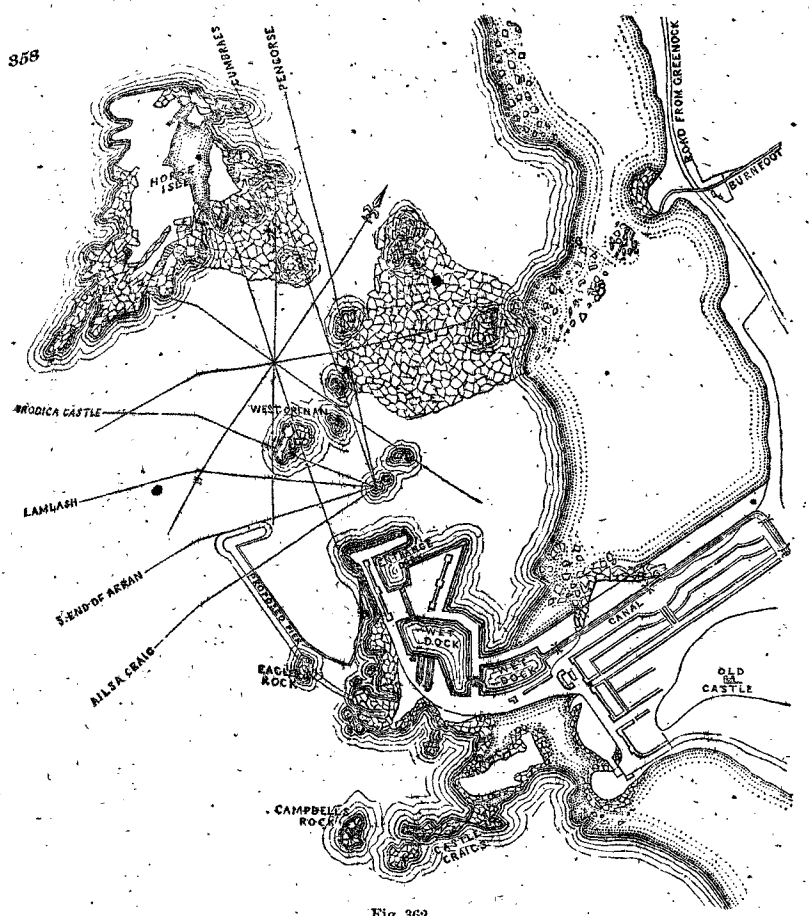


Fig. 362.

These works were directed by Mr. Telford, who employed chains and wooden cranes for raising the large masses of stone used.

Troon has a mole, built in the form of a horse-shoe, the outside and inside courses of which are composed of granite, cut at right angles with the joints, and left rough externally. The several courses lie with an inclination of 45°, which occasions the seas to glide off more easily. There is a large wet dock, of a quadrangular figure, also built of granite, and the entrance is from the north. To the east is a building dock, with gates 36 feet wide.

Ayr Harbour is at the mouth of the river of that name, where it falls into the wide and open part of the Firth of Clyde, where the coast is flat, and composed of drift sand, which has formed a bar before the mouth of the harbour; the river, which is of a considerable width and force, and subject to great speats in rainy seasons, drives the sand out to sea, and prevents the entrance from being entirely choked up.

By the erection of the north and south dikes or walls, the channel of the river has been confined, and made to pass over the flat sands, which has maintained a tolerable depth of water in the harbour.

When Smeaton saw this harbour in the year 1772, he advised the raising of these walls to the level of high water mark, and that they should be so lengthened that a greater force might be obtained, and the back waters being driven in a north-west direction might be prevented from acting on the banks; he calculated that by judicious management a considerable additional depth of water might be obtained.

The harbour commences below a bridge of four arches, and two piers of stone and timber extend 550 yards right and left of the river, to which the vessels are moored.

In the town of Ayr, Cromwell established a fortress.

Carlisle on the Eden is situated some distance beyond Maryport, which is at the mouth of that river, the banks of which are protected by stone quays and wooden piers.

Workington is a small port at the mouth of the Derwent, here crossed by a bridge of three arches, which does not interrupt the passage of small vessels to Cockermouth, a town on its banks, where the Cocker enters.

Whitehaven is a port with a lighthouse and mole, of considerable business, and the coal works in the neighbourhood give employment to numerous coasting vessels.

Ravenglass, at the mouth of the Esk, has a deep gulf, extending to Ulverstone, where are numerous manufactories.

Lancaster on the Loyne has a harbour, whose entrance is obstructed by a bar thrown up by this torrent stream. On the left bank of the river there is a long quay for the accommodation of the shipping.

Preston, situated on the Ribble, at a short distance from the sea, carries on a considerable trade.

Liverpool, on the Mersey, ranks next to London in point of importance and commercial wealth, although Leland tells us that in his time (Henry VIII.), "Lyverpoole, a paved towne, hath but a chapel. Walton, a four miles off, not far from the Le, is paroche chirch." Irish merchants then resorted to it, on account of its small port dues. From the time of William III. this place has continued to increase in importance. Situated on the eastern bank of the estuary, it has long been considered the key of its commerce: the river gradually widens towards the sea, and at spring tides the water rises 30 feet, and at dead neaps only 13 feet.

The shore, however, is remarkably flat, and though vessels rode safely in the offing, it was found necessary to form a more secure place for them; and in the reign of Queen Anne the first floating dock for ships, called the Old Dock, was constructed; in the reign of George II. the Salt House Dock was formed, and a pier erected.

In the following reign St. George's Dock was formed; piers to secure the outer harbour, and two new lighthouses, were built. The King's, Queen's, and other docks have been since added, as have graving-docks and dry basins for the convenience of the shipping resorting here.

These docks were the first constructed in England for the accommodation of merchandise, and consist of wet, dry, and graving; the latter, by means of flood-gates, can admit or exclude the entrance of water at pleasure.

The Old Dock is 198 yards by 85 yards; Salthouse Dock 213 yards by 102 yards; St. George's Dock 246 yards by 100 yards; King's Dock 272 yards by 95 yards; Queen's Dock 280 yards by 120 yards.

The principal basin of the West India Dock measures 2600 feet by 510 feet, and is 29 feet deep; contiguous to it is another of the same length, 400 feet wide; the first contains 30 acres, and will hold nearly 300 sail; the latter contains 24 acres, and is used for the vessels about to proceed outwards.

The London Dock, for unlading, is 1262 feet long, 699 feet wide, and contains about 20 acres.

The East India Dock, for unlading, is 1410 feet long, by 560 feet wide, and contains 18¼ acres; that for loading is 780 feet long, 520 feet wide, and contains 9½ acres.

Between all these docks there is a communication, so that vessels pass from one to the other, and into the several graving-docks, without going into the river.

Large tunnels pass from one dock to the other, for the purpose of scouring them; so that when a dock is to be cleansed, it is left dry at low water by closing the gates; the sluices are then opened in different directions, and a number of navigators enter with spades and shovels, to throw the mud into the channels or currents made by the sluices; this, continued for several days or a fortnight, once in the year, keeps them tolerably free from accumulation.

Formerly such an operation was effected by means of flat-bottomed boats, and the sluicing here introduced was a vast improvement.

The Bridgewater Dock is for the use of the barges that belong to the several canals.

The five old docks, without including the Bridgewater basin, and the two others, have 3600 yards in length of quay, or a superficies of 28 acres. The dimensions of these docks were increased by the late Mr. Rennie to an area of 62 acres; this was effected by suppressing one dock, enlarging three others, and constructing two new ones, one to the north, and the other to the south.

The new bridges are on the best principle, and the cranes of superior construction: the capstans for opening and shutting the gates, the rollers and chains, are all of iron.

The distance between the quay at Manchester and these docks is 33 miles; but the channel or natural course in the Mersey was 15 miles further; but this has been lessened considerably, and reduced now to a little more than 41 miles.

At Manchester the river is 108 feet in width, at Warrington 140 feet, at Fidler's

Ferry 170 feet, and at Cuerdly Point 650 feet: from thence it rapidly widens to 3500 feet; it is then narrowed at Runcorn Gap to 1200 feet, and at a short distance beyond its width is 4200 feet, after which it extends to nearly 2½ miles, and is again diminished at Liverpool to 3300 feet.

The level of the highest tide intersects the bed of the river at Woolston, a distance, by the course of the channel, of nearly 26 miles; and the bed of the river at Manchester is 49 feet above the bed of the river at Woolstan. At Warrington is the first weir, after which the distance to Manchester is divided into ten pools.

At Liverpool, the spring tides rise 33 feet, at Runcorn 16 feet 6 inches, and at Warrington 8 feet. The lowest of the neap tides at Liverpool is 23 feet 6 inches, and the depth of water with a high spring tide is 89 feet; but the bed of the river rises so much that at 9¼ miles there is only 33 feet.

Birkenhead, on the Mersey, nearly opposite to Liverpool, on the Cheshire coast, is becoming a port of great importance; the formation of numerous docks, and the rapid increase of its inhabitants, have occasioned a new market, a town hall, and various other public edifices to be erected. The area of the market is 430 feet in length, and 130 feet in breadth; its roof is supported by forty-six cast-iron columns, 25 feet in height.

Aberconway has a small port or dry harbour, and its ancient town of Conway, surrounded by high walls 12 feet in thickness, with twenty-four circular and semi-circular towers, give us some idea of a Greek or Roman city. The walls and four gateways remain, now inclosing a wretched collection of dwellings. On the eastern side of the wall of the town is a quay of some extent; and here was a ferry of so much importance that it formed the landing-place for those who returned from Ireland. The spring tides rise about 12 feet, and at low water the river Conway is not more than 150 feet in breadth. The sandy bed of the river still produces the pearl oyster or muscle, as it did in the time of the Romans, and the limestone in the neighbourhood abounds with copper ore.

Bangor, so famous for its slate quarries, is situated at the Menai Straits, which separate the Isle of Anglesea from the main land.

Caernarvon, the Segontium of the Romans, is highly interesting to the antiquary for the remains of the ancient city, which occupies an oblong square, containing seven acres at a short distance from the present town.

The port affords excellent anchorage in 10 or 12 fathoms of water, although the Aber sand bank forms a dangerous bar to vessels entering. The quay is of considerable extent on the side of the castle, and has lately been greatly improved.

Beaumaris, a port of the Isle of Anglesea, has considerable trade, and in the neighbourhood are rich and extensive copper mines.

Menai lighthouse, constructed on a sunken rock about 200 yards from the coast of Anglesea, was designed by Messrs. Walker and Burgess, and its total cost is said to have been 12,800*l*.

It resembles a circular tower, 40 feet in diameter, 75 feet in height, and 20 feet 6 inches in diameter at top, where it is capped by a castellated parapet of Anglesea marble. The base of this tower is solid to the height of 22 feet 6 inches, after which the walls diminish at regular sets-off, of 9 inches each, and at the level of high water the diameter is 22 feet.

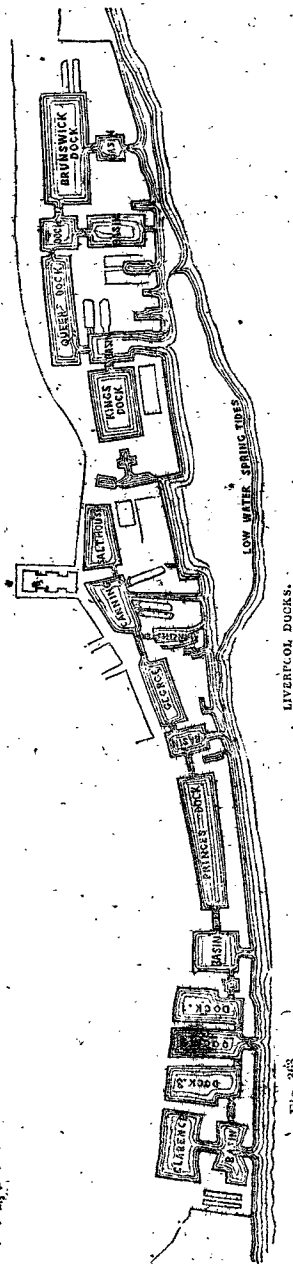


Fig. 363.

The interior is divided into six stories; all the stones are laid perfectly water-tight, and are each secured to the one below by a slate joggle, and two oak trenails passing

entirely through it, and entering 8 inches into the lower stone. On the upper bed of each course is a projecting fillet, which enters a groove formed to receive it in the upper course, and by this means no water can be admitted. A gallery is formed above by projecting the courses inside and out; this supports the lantern, which is of cast-iron.

The light is stationary, red, dioptric, of the first order, without mirrors. The burner has four concentric wicks, the largest of which is 3¼ inches in diameter, and consumes a pint of oil per hour. The mortar used in the construction consisted of three of sand, one of lime, and one of pozzolana. A foot-bridge unites this lighthouse with the shore. On a rock at a short distance is a beacon formed of a cone of masonry, 20 feet in diameter at the base, and 37 feet high: on the top is a staff and globe, which rise 13 feet above the apex; the globe, 4 feet in diameter, formed of copper bands, is 36 feet above high water mark.

Lighthouse lamps, as now supplied with oil, are of the Argand or Fresnel construction, and great attention is requisite to the ventilation of the chambers; where a quantity of oil is burnt in a short space of time a great quantity of carbonic acid is produced, which renders the atmosphere unwholesome. A pound of oil in combustion produces 1·06 pounds of water, and 2·86 pounds of carbonic acid; this increase of weight being due to the absorption of oxygen from the atmosphere, one part of hydrogen taking eight parts by weight of oxygen to form water. An Argand gas-burner in four hours, when placed in the window of a shop, produces 2½ pints of water. Lighthouses are now usually fitted with one large central lamp, the outer wick of which is 3 or 4 inches in diameter, or with many single Argand burners, each having a parabolic reflector. Professor Faraday has contrived a method to keep the air in the chamber pure, and to ventilate the lamps by flues which maintain fresh air within the lantern; this is performed by means of a chimney or copper tube, 4 inches in diameter, not in one length, but in three or four; the lower end of each portion, for about 1½ inch, is opened out into a conical form, measuring 5½ inches in diameter at the lowest part. When these pipes are put together to form the chimney, the upper end of the bottom piece is inserted about ½ inch into the cone of the next piece above, and fixed there by three ties or pins, leaving at the same time plenty of air-way.

After the ventilating chimney is thus completed, it is placed in such a manner, that the lamp chimney enters about ½ inch into the lower cone, and the top of the ventilating chimney enters into the cowl or head of the lantern. The ventilating flue, thus ingeniously contrived, is found to carry off all the products of combustion into the cowl; none passes into the conical apertures from the flue into the air of the lantern, but a portion of the air passes from the lantern by these apertures into the flue, and thus ventilates it.

A sudden gust of wind striking the cowl does not in any degree affect the steadiness of the flame, the ventilating flue carrying up every thing, and bringing nothing down. In lighthouses, where many separate lamps and reflectors are made use of, a system of gathering pipes is resorted to; these are brought together behind the reflectors, and enter one large pipe, which passes off to the cowl at top. A seven-eighth inch pipe is found sufficient for a single lamp, and this is made to pass downwards through the aperture in the reflector over the lamp, and dips an inch into the lamp glasses, when the draught upwards is such, that not only do all the products of combustion enter the tube, but air also passes down between the top edge of the lamp-glass and the tube, and is finally carried off with the smoke. The tube should not dip more than ½ inch into the lamp-glass, or the whole of the burnt air would not escape.

Holyhead, or the Caer Cybi of the Britons, is situated on a small island at the north-west extremity of Anglesea; here are the remains of many Roman constructions, as well as British. This port, being the nearest to Dublin, has occasioned it at all times to be much frequented; latterly it has undergone considerable improvement, and a new lighthouse been erected. The piers in front of the port are upwards of 1300 yards in length, and the base 90 yards in breadth. The slope towards the sea is made 5 to 1, and the breadth at top is 8 feet. At 8 feet below the top a way is formed, 48 feet in breadth, which answers the purpose of a quay. At the end of the pier the quay is 47 feet above the level of low water mark, and 6 feet above high water. All the masonry is executed with granite obtained in the vicinity, and towards the head of the pier is formed a jetty or spur which advances 60 feet, and has a width of 164 feet.

It appears from Tacitus (in Vita Agricolæ), that the Romans had a settlement here, and carried on a considerable trade with the people of Ireland. No place could be more advantageously situated for such a purpose, as it projects far into the Mare Vergivum of Ptolemy, and lies in the neighbourhood of the Roman stations on the western shores of Flavia Cæsariensis: Mr. Pennant has described a Pharos at the summit of the mountain called Pen Caer Cybi, 10 feet in diameter, and at no great distance a regularly faced wall, 10 feet in height and 6 feet in thickness, which surrounds three sides of a parallelogram, the fourth being open to the harbour. At each angle was a circular tower. By some these fortifications are supposed to be the work of the celebrated chieftain Caswallon Law-hir, for the purpose of repelling the Picts, who infested these coasts after the final departure of the Romans.

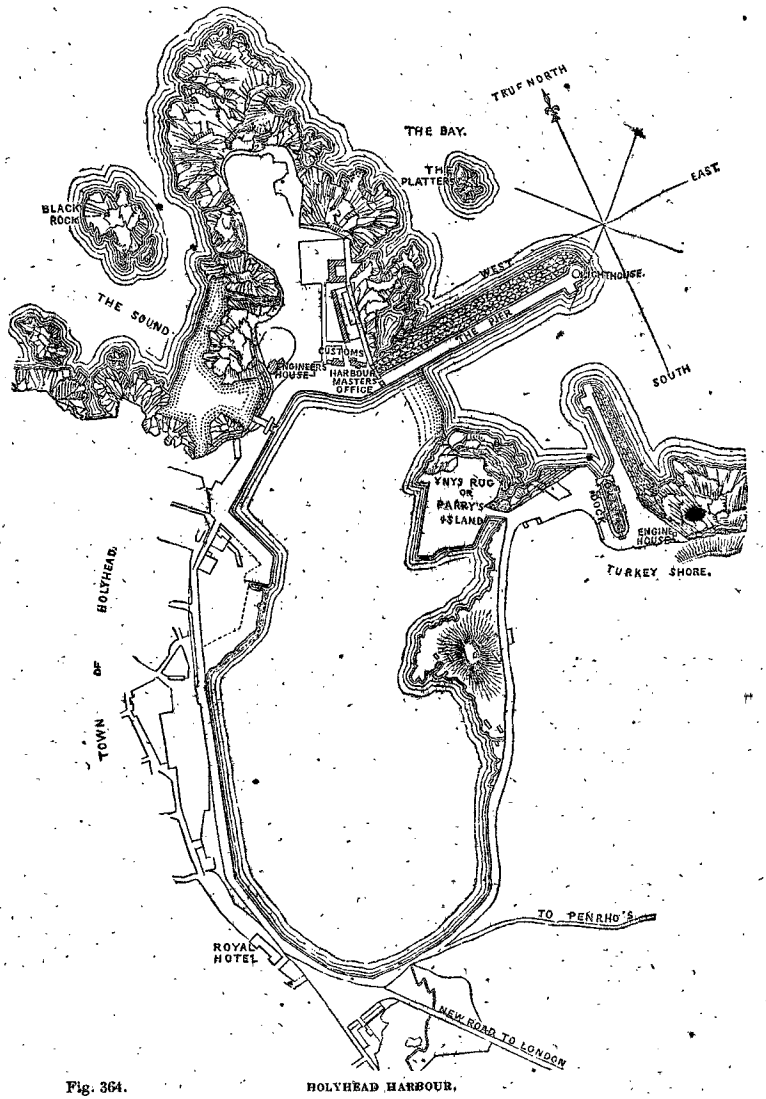


Fig. 364. HOLYHEAD HARBOUR.

Towards the south is another pier, and within is a wet dock, containing upwards of 22 acres, with a depth of water of 19 feet. To the south of the port, on the rocks, stands one lighthouse, and another is placed at the head of the mole.

Aberystwith has a small port, and in the neighbourhood are extensive lead mines, which afford employment to the shipping.

Milford Haven, surrounded by lofty mountains, penetrates far inland, and has sufficient depth of water for the largest vessels of war. At Pembroke is an arsenal.

Swansea, an excellent seaport, formed by the construction of moles, by Captain Huddart, is situated on the western side of the river Tawe.

Cardiff is a port at the mouth of the Taff, about three miles from Rumney Bridge, and the town was once surrounded by thick and lofty walls. The new cut to the quays admits

shipping of 200 tons; in the neighbourhood are many canals and railroads, which greatly contribute to the business of this port.

Bristol is one of the most important cities of the empire, and the great emporium of the western counties; in the eleventh century, we find its inhabitants trading with Ireland, Norway, and every part of Europe: though the city is situated at a distance of 8 miles from the ocean, yet the Avon and Frome are of sufficient importance to allow vessels of any burthen to arrive at it. The quay and harbour have received improvements at various times, and a company was established in 1804, that undertook the formation of extensive docks, which were completed about five years afterwards, covering 82 acres of ground; they extend 2½ miles, and at all hours vessels may pass from Dunhead to the quays, and discharge their cargoes while afloat: the arms of Bristol, which consist of a ship and a castle, have the motto *Virtute et industriâ*, which should be ever remembered by commercial men.

The Frome, below its junction with the Avon, resembles a vast basin, which traverses the greater part of the city; around this artificial port are a range of quays. The vessels coming up the Avon are first admitted by a lock into an entrance dock, called Cumberland lock, which can be made dry; then, by a second and third lock, they enter the great basin.

The Cumberland dock is built of stone, and its subterranean aqueducts, with elliptical openings, are admirably contrived for sluicing and clearing away the mud. Here are docks for building and careening vessels, spacious timber-yards, and numerous basins, where ships may always remain afloat.

This port is greatly indebted to the skill and knowledge displayed by its engineer, Mr. William Jessop, whose father was engaged to superintend the erection of the Eddystone lighthouse, under the direction of Mr. Smeaton; the engineer employed at Bristol was born at Plymouth, in the year 1745, and died in 1814; the improvements he made were highly important, and chiefly consisted of the conversion of the river Avon into an immense floating dock, which extended over 70 acres; this was effected by diverting the river Avon for a length of two miles, and then cutting a canal to carry off its waters at the back of the city; by such a project three miles of the rivers Avon and Frome were converted into a deep wet dock, an entrance basin, with double lock chambers opening into the Avon below, and a single chamber into the old river above.

Bridgewater is a port where the tide rises 40 feet, and frequently occasions damage to the shipping. The most considerable portion of the town formerly occupied the east side of the river; now it is on the western; there is an ancient bridge of three arches, built in the reign of Edward I., to the north of which is the quay.

Watchet and *Minehead* are two small ports on this coast, and from the first named is shipped the lime so celebrated for hydraulic purposes.

Ilfracombe has its port, surrounded by a semicircle of hills, which contribute much to its security.

Barnstaple, at the mouth of the Taw, is a town of importance, and vessels can safely anchor under its long and spacious quay, which extends for a considerable distance beyond a bridge of sixteen arches, which crosses the river. At the mouth of the Tawe a bar is thrown up, which prevents vessels exceeding 200 tons entering the river.

Bideford is another port, south of Bristol, where merchant vessels may anchor alongside a spacious quay, built at the side of the river.

Hartland is a small artificial port, built in the reign of Elizabeth, for the convenience of the fishermen frequenting this coast.

Padstow, on the south bank of the Camel, is the best port on this coast; here is a channel for ships at low water, 18 feet deep, and 400 feet in width; and vessels can at all times come alongside the quay, and to the custom-house built adjoining it.

St. Ive's Harbour is situated five leagues north-east of Cape Cornwall, and upon the entry of the British Channel lies nearly opposite Mount's Bay; this harbour is in depth about 2 miles, and in width 4 miles, having in the middle, at low water, full 10 fathoms. The bottom is clean, and composed of a fine white sand, or the fragments of sea-shells; underneath this is a blue clay, forming excellent anchorage ground. A bold rocky promontory, called the Island, is situated at the north-west corner of the bay; this is joined by a narrow neck to the main land, and projecting towards the east forms an harbour on the north-west side of the bay, which is well defended from all winds, except those from the north-east. This interior harbour is almost left dry at low spring tides; but the fine soft sand that lines the bottom of this bay affords an easy bed for ships when left by the tides; for larger vessels there is an excellent road, where they may ride safe from all north-westerly, westerly, south-westerly, southerly, and south-easterly winds, in 6 or 7 fathoms of water, at low spring-tides. Mr. Smeaton visited this port in the year 1766, and furnished a design for a pier, 60 fathoms in length; and he advised that if upon an examination of the soil, there should not be found any rock upon which the foundations might be laid, they should work upon the principle the French call *pierre perdu*, or cast-stones, that is to

say, by dropping a large quantity of rough stones in a proper direction and width, so as to form an artificial rock or base for the pier; these stones, sinking by degrees into the sand,

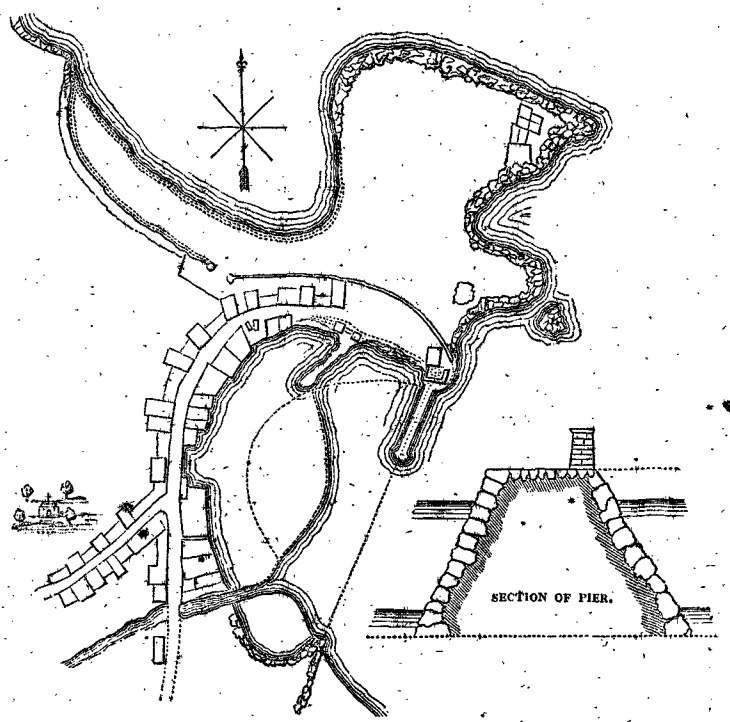


Fig. 365. ST. IVES HARBOUR.

and being followed by others, will rest upon the former, and so on, till the lowest become firm; for the sand, lying very close and compact, will bear any weight when not affected by the action of the sea. By this method more stone is required than if the pier be built upon a regular base; but the whole being of very rough stone, and executed without timber work, it will be cheaper and more secure than any thing can be made upon a foundation of piles and timber upon sand.

The pier, so raised to half tide, or even to the top, was to act as a breakwater or defence against the sea, and Smeaton estimated that the cost would be 7*s.* 6*d.* per cube yard.

The highest spring-tides being 26 feet above the surface of the sand, the pier was to be carried up solid to the height of 30 feet; and supposing the settlement in the sand to be 6 feet, the whole height would be 36 feet. The pier was to batter half its height on each side, and as the top was to be 24 feet in breadth, the base would be 60 feet, and the mean breadth 42 feet; this multiplied by 36 feet, the height, gave a sectional area of 168 yards.

Smeaton recommended that the shores should be planted with sea rushes, which were found to entangle the sand, prevent its blowing about, and retain it in the north bay, where it arises, and by this means the breadth of the neck of land that joins the island would be increased.

Penzance harbour has a mole to protect it, but the port is dry at low water.

Falmouth has a spacious port and quay, from whence the packets bound to Spain, Portugal, and the West Indies, take their departure.

Fowey is a small port at the mouth of a river of that name, and the town is built upon its western bank.

Plymouth Sound, on entering, has to the east the celebrated breakwater; after passing which a natural basin is arrived at, into which the Tamar and Plym discharge themselves, forming the harbour, comprehending the three divisions of the Hamoaze, the Catwater, and the Sound.

In the time of the Saxons, this haven was called *Tameorweth*; by the Normans South Town, and in the reign of Henry VI. it received the name of Plymouth. We have an

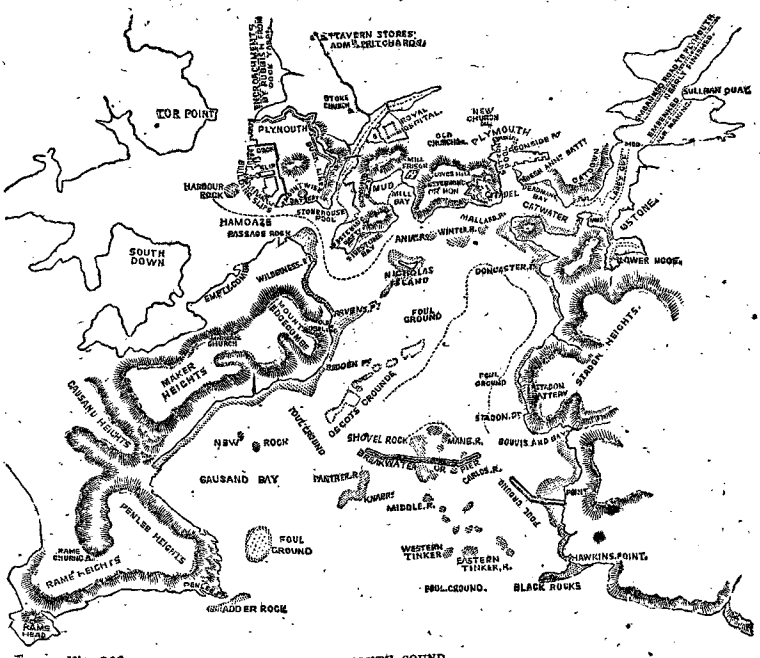


Fig. 366. PLYMOUTH SOUND.

account of the town in the reign of Elizabeth, and of its new charter, then granted at the request of Sir Francis Drake, who brought water to all the houses by means of leaden pipes from a reservoir which he formed above the town, the property of which he vested in the mayor and commonalty, and their successors for ever. The water was conveyed to the reservoir, through a winding channel of 24 miles, from some springs at Dartmoor; this enterprise of the gallant admiral is perhaps the earliest example in England of supplying a town with water brought from a distance.

Plymouth has had at various times considerable fortifications erected around it for its security: its most ancient fort, built in the reign of Edward III., is by Leland styled "a strong castel quadrate, having at each corner a great round tower." This fortress, which stood on the south of the town, near the pier, is now nearly demolished, as are the numerous block-houses which were erected at different points of the harbour in the time of Queen Elizabeth. Some traces of them may perhaps yet be seen on the site of the fort which occupied Hoe Cliff, where the citadel now stands. The view from the citadel comprehends Maker Tower, Mount Edgcumbe, the town of Dock, now Devonport, Mount Wise, and the Tamar, the beautiful bay of Causand, the Sound, the Bristol Channel, and, in fine weather, Eddystone lighthouse, the scenery around Saltram, Plympton, Mary Vale, and the lofty hills of Dartmoor.

St. Nicholas Isle, also fortified, is connected to the south-west shore by a range of rocks, which are uncovered at low tides. Near the Devil's Point is the victualling offices, where are granaries, bakehouses, and every requisite for the supply of a large navy. The docks, situated about 2 miles from Plymouth, on the eastern bank of the Hamoaze, are defended by strong fortifications, and acknowledged to be the finest examples of a maritime establishment in the world: they contain upwards of 72 acres, and are surrounded by a stone wall 30 feet high. Basins, docks, slips, rigging houses, artificers' shops, mast-houses and ponds, rope-houses, mould lofts, and all that can be deemed necessary for the navy of a great nation, are provided on a most perfect and extensive scale.

The basin, made in the reign of William III., has within it a dock 198 feet in length, 66 feet wide, and 23 feet deep.

Adjoining the south jetty are the rigging-houses, 480 feet in length, three stories high; and on the other two sides, forming a square, are various store-houses. Beyond these, to

the south, is a slip for hauling up and graving the bottoms of ships, and farther on is a canal 70 feet wide, which has a basin at the upper end for small boats. An anchor manufactory and smith's workshops adjoin the wharf, near which are three slips; northward lie the mast-house and pond. The rope-makers' buildings are 1200 feet in length, and two stories in height; in the upper twine is made, and in the lower cables are *layed* or twisted together, the largest of which are more than 24 inches in circumference, and weigh upwards of 8 tons.

The double dock, situated near the north jetty, will contain two vessels, lying one a-head of the other, but divided by gates. The Union dock, 240 feet in length, 87 feet wide, and 27 feet deep, is faced with Portland stone, having blocks of granite to support the shores.

The New Union or North New dock is 260 feet long, 85 feet wide, and 28 feet deep, and these, as well as the whole of the work executed before the year 1790, were by Mr. Barlby.

Plymouth Breakwater is composed of three arms or bends; the centre is in length 3000 feet, and each of the others 1050 feet, both inclining on an angle of 20 degrees. The length

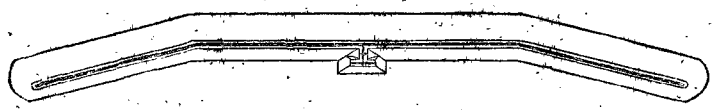


Fig. 367. PLYMOUTH BREAKWATER.

of the whole, measured at the top, is 5100 feet, and at low water line 5310 feet. At the western extremity, a circular foundation was prepared, to receive the lighthouse, 570 feet in diameter. The general depth of water varies from 36 to 60 feet at low water spring tides, which generally rises about 18 feet, and at neaps from 12 to 14 feet.

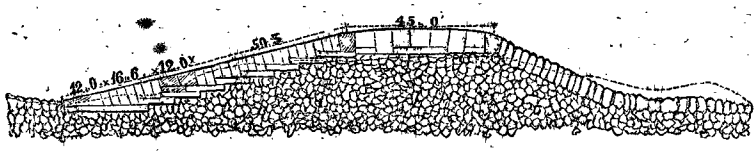


Fig. 368. SECTION THROUGH BREAKWATER.

This work was executed by Mr. Rennie, in the centre of Plymouth Sound, the first stone being deposited on August 12. 1812. The entrance into the harbour on the eastern side is ½ mile in width, and here there are 6 or 7 fathoms of water: the western, which is the entrance most used by the shipping, is about the same width, and varies in depth from 7 to 9 fathoms at low water spring tides.

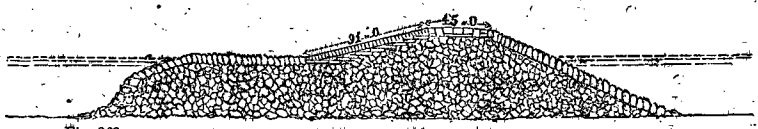


Fig. 369. SECTION THROUGH BREAKWATER.

The work is chiefly composed of limestone obtained at Oreston, about 4 miles distant, where the quarry is situated at the mouth of the river Laira.

The exterior slope, below the line of low water, was formed by the sea, and is now ascertained to lie at from 3 to 4 feet horizontal to 1 of perpendicular; and from the low water line upwards, it is 5 to 1. The inner slope is 2 feet horizontal to 1 of perpendicular from the base to the top, which is laid 2 feet above high water spring tides. The width here is 45 feet, and in the centre it forms a ridge 12 inches higher. Beyond the slope towards the sea there is an additional work or foreshore 30 feet in width at the east end, 50 feet in the centre, and 70 feet at the west end; this rises about 5 feet above the level of low water, and is intended to diminish the force of the sea, and to prevent the undermining of the chief work beyond it.

The stone was raised in large blocks, some of which contained 10 tons, and were thrown into the sea, in the direction set out for the breakwater, care being taken that the greater number were deposited upon the outer slope. After a number of these large masses had been lowered, a smaller class of stones, quarry rubbish, rubble, and lime screenings, were thrown in to fill up the interstices, and close all the cavities; these found their position, by the action of the sea, and the great mass became as it advanced perfectly wedged together; in the storm which occurred in November, 1824, the sea made the outer slope

5 feet to 1 perpendicular, and drove all the rubble from the outer to the inner slope, making its area equal to the other. Time was requisite to give the whole its perfect consolidation, which being obtained, and no movement in the masses being apparent, the slope on the side towards the sea down to the foreshore was cased with regular courses of masonry, which was dowelled, joggled, dovetailed, and cramped together, to lay the lower courses of which the diving bell was made use of. The three lower courses were all granite, laid horizontally on their natural beds; these were dovetailed, lewised, and bolted to each other. The mortar was compounded of one part of Italian puzzolana, one part Aberthaw lime, mixed with two parts of fine sharp freshwater sand: this composition, before it was used, was well worked together in a mill, with as little water as possible: this, when applied to the masonry, speedily became hard. Roman cement was employed for the outer joints and for some distance within, and to increase its setting. For the interior of the work, a concrete was made use of, composed as the first, but with a greater quantity of sand.

To transport the stone from the quarries to the breakwater, vessels of about 60 tons' burthen were employed; these had two railways laid along them, parallel to each other, and towards the stern they formed an inclined plane, which prevented the trucks from running too far. The blocks of stone were placed upon trucks, and then in parallel lines on the railways. After the vessel had arrived at its destination, the trucks were discharged of their load by heaving them up; this was done by windlasses placed on the deck; when the truck had arrived at the inclined plane, it was tilted over by its own weight, and the stone was at once let go, and deposited into the sea; the truck then made way for another, and after the whole was discharged, the vessel returned, to be again freighted at the quarry: to economise time, steam-tugs were made use of, and consequently many voyages were performed in a day. To guide the vessels, and to enable them to shoot out their load in the proper place, buoys were laid down in the line at every 30 feet; an account was kept of the quantity deposited, and the level it rose to, so that at all times the actual state of the work was known.

This important work is so situated, that vessels can enter the Sound with either an easterly or westerly wind; and the two entrances are so set out, that the tidal and fresh water keep them at all times clear, and prevent any deposit or accumulation of sand from obstructing them.

The heaviest gales are those from the south and west, when the breakwater is exposed to the whole violence of the vast Atlantic; hitherto it has been found to stand against this power, and effectually to check the waves which uninterruptedly roll through the Bay of Biscay. 3,369,261 tons of stone are computed to have been used in this stupendous undertaking from the year 1812 to March, 1841, when it was completed at a cost of nearly 1½ million sterling. A calculation has also been made upon the entire cubical contents as compared with the quantity of stone deposited, and it is found that the interstices occupy about 37 per cent. of the whole, which arises from the employment of large blocks of stones.

Messrs. Walker and Burgess have constructed at the western end a lighthouse, designed by the late Mr. Rennie. The dimension of this lighthouse, which is circular, is 14 feet clear diameter, and the centre of the light is placed 55 feet above the top of the breakwater. It is built of granite, and divided by floors into store, dwelling, bed, and watch rooms. The lantern is 12 feet in width, and 7 feet 6 inches high, in which is a dioptric fixed light with mirrors; the south side shows red lights, and the north white, which distinguishes it from the other lights on the coast.

Where this lighthouse is placed, the diameter of the head of the breakwater is 390 feet at the level of low water, and at the top 75 feet. All the lower courses are secured with slate dowels, and vertical and horizontal dowels 18 inches long and 6 inches square at the centre, sunk 8 inches into the lower course of stone; both ends are also dovetailed, and secured in their places by plugs of copper, and by wedges driven into the lower stone.

Eddystone Lighthouse is built upon a rock, which lies nearly south-west from the middle of Plymouth Sound, according to the true meridian; and the nearest point of land is the promontory called Ramhead, which is distant about 10 miles, and bears from thence south scarcely one point west, or, by the compass, south-west by south, allowing two points of variation of the north end of the magnetic needle to the westward. These rocks have derived their name from the set or current of the tides which are observed there. An eddy of the tide is a current setting in a direction contrary to the main stream, and is occasioned by some obstruction; this eddy may be either a smoothness on the surface of the water, or a current in the opposite direction to the tide, according to the velocity of the stream, or the size of the island or rock which interposes to produce it.

The rocks are situated in west longitude 4° 5′, and north latitude 50° 10′, and consist of three principal ridges, called the House, South, and East Reefs. They lie north and south, in which direction their greatest extent is 600 or 700 feet; there is also a small rock, called the North-east, seen only in spring tides, which lies about 1000 feet from the House Rock. They are either granite or gneiss, called in Cornwall moorstone; they

abound with felspar, which is of a brownish colour, and contain a number of irregular-shaped white specks; they dip towards the north-west, at the rate of about one perpendicular to two horizontal.

On the days of full moon it is high water at the Eddystone at a quarter past five o'clock; the tide of flood sets easterly, or up Channel, and the ebb tide sets westerly; spring tides rise from 16 to 18 feet, and neap tides from 10 to 11 feet: at these rocks, and upon the opposite shores, it is high water about 2½ hours sooner than in the middle of the Channel.

The first lighthouse was commenced in the year 1696 under the general powers lodged in the Masters, Wardens, and Assistants of the Trinity House, who were empowered in the reign of Elizabeth to erect and set up beacons, marks, and signs for the sea, needful for avoiding the dangers, and to renew, continue, and maintain the same.

Mr. Henry Winstanley, of Littlebury, in the county of Essex, was the engineer bold enough to undertake this building, which occupied three years in constructing; he commenced by making twelve holes in the rock, and introducing as many irons 3½ inches in diameter, around which he carried up a mass of masonry 14 feet in diameter, 12 feet high upon the upper side, and 17 feet on the lower; on this was constructed the upper stories, which were probably of timber.

The base was afterwards increased, so that its diameter was 24 feet; above this, the structure had a polygonal form of twelve sides, and the upper or look-out room had eight; the whole underwent a thorough change, or reconstruction, and the lighthouse, as completed in 1699, bore no resemblance to the first design.

On November 26. 1703, a violent storm carried away the lighthouse; and Mr. Winstanley, the workmen employed in its repair, and the light-keepers, all perished.

Mr. John Rudyerd, a silk-mercer upon Ludgate Hill, was in the year 1706 employed to reconstruct it; and whatever he required as a mechanist was ably supplied by two shipwrights from the king's yard at Woolwich. A circle was the form he selected for the plan of the new building, and after making a number of holes in the rock by means of jumpers, he inserted the iron branches, to hold his work firmly to the foundations prepared for it. The holes were 2¼ inches in diameter, and the extremities of the two which formed the breadth for the branch at the surface of the rock were about 7½ inches, and these holes were bored slanting, so that at the bottom they were full 8½ inches apart. Between every two holes was bored a third, and afterwards the rock between them was broken away by square-faced pummels, when a hole of a dovetailed shape was obtained 2½ inches wide, 7½ inches broad at top, and 8½ inches at bottom, and in depth 15 or 16 inches. These holes were not exactly alike in dimension, and it became necessary to forge an iron expressly to fit each.

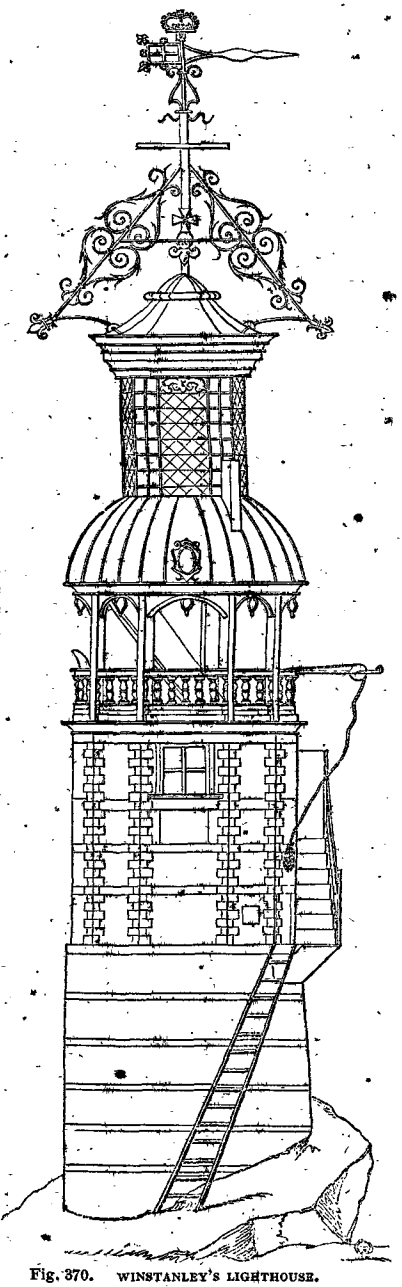


Fig. 370. WINSTANLEY'S LIGHTHOUSE.

The main pieces of each branch were, at the surface of the rock, 4½ inches in breadth, and at the bottom 6½ inches; when introduced into the hole, there was space left to admit a key, which, at the bottom, was 2 inches, and at the top 3 inches, which, when driven, fixed the whole in the manner of a dovetail or lewis.

The holes being fitted with the branches, a quantity of melted tallow was poured into each; the branch and key being heated to a blue heat was put into the tallow, and the key firmly driven, so that the space which the iron did not occupy was filled with tallow; after this was done, and whilst the iron was warm, a quantity of pewter, made red-hot, was poured in from a ladle, which being heavier than the tallow drove it out. Many years afterwards, when these irons were cut out, the iron, pewter, and tallow were found unaffected by the action of the sea-water, which apparently had never penetrated into the holes which contained them.

After these irons were fixed, a layer of squared oak timber was placed lengthways upon the lowest step of the rock, and of a depth to reach to the level of the next above. Over these were laid crosswise another layer of timber; and above this, others, taking care to cross each alternate course, until a mass of timber was piled up two complete courses higher than the highest part of the rock, and these were all trenailed together. In the middle of this series of timber platforms stood an upright mast, which was firmly secured to the rock by two stout irons; this mast served as a centre for guiding all the rest of the superstructure, as there were altogether 36 of these branch irons, in each of which was bored a hole, seven-eighths of an inch in diameter, and through these 252 holes passed as many bearded spikes, or jag bolts, which held the several layers of timber together.

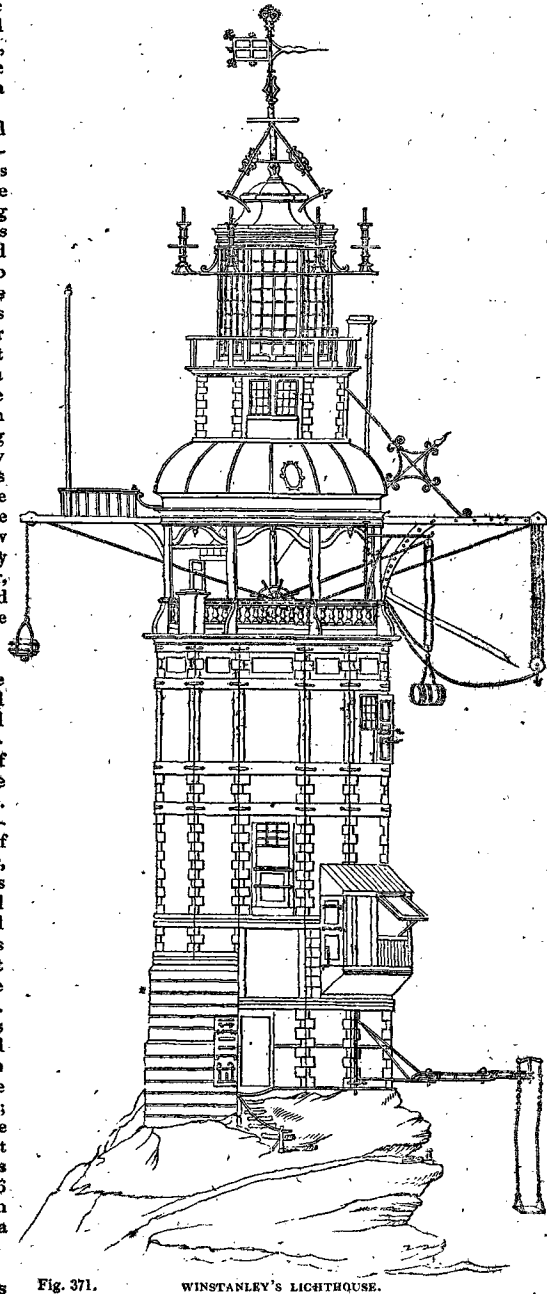


Fig. 371. WINSTANLEY'S LIGHTHOUSE.

Two courses of solid oak timber, squared, were laid one upon the other, to form the basement; and on this five courses of Cornish moorstone, each a foot in thickness; these were well jointed, but laid without any mortar or cement, and retained in their place by iron cramps; the outer courses being further bound together by upright ones, which also prevented their being lifted by the action of the waves.

After this 5 feet of moorstone was laid on, which weighed 120 tons; two other courses of timber crossed them, and where the timbers presented their ends, circular or compass timbers were laid, which were scarfed together, each course breaking joint over the other; these outside timbers were jag-bolted to the interior parallel pieces.

Above the basement so constructed, a well-hole, 6 feet 9 inches square, was left for the stairs; and at 8 feet above the highest part of the rock commenced the step of the entrance doorway.

After constructing the building with courses of moorstone and layers of compass timbers up to the top of the central mast, the height of which was 33 feet, a floor was laid over the whole, composed of 3-inch oak plank.

The upper part of the building comprised four rooms, one over the other, formed of upright timbers, having a kerb or circle of compass timber on each floor, to which the upright timbers were screwed or connected, and upon which the floor timbers rested. These upright timbers were jag-bolted and trenailed to one another, and in this manner the whole was carried up to the height of 34 feet above the floor, which was placed over the top of the central mast. The floor of the lantern was made of 3-inch oak plank, around which was fixed the balcony.

The whole building was in form the frustum of a cone, 22 feet 8 inches in diameter at the bottom, and 14 feet 3 inches at the top, and the height above the circular base was 61 feet; so that the base was a little more in diameter than one-third of its height, and the diameter at top was somewhat less than two-thirds of the base at the greatest circle. The upright timbers were united at the ends by scarfing and overlapping; they varied in length from 10 to 20 feet, but were so united that no two scarfings came close together. The number of uprights around the entire building were 71, their breadth at the bottom nearly 12 inches, and their thickness 9 inches, diminishing towards the top, both in breadth and thickness. All the outside seams were well caulked with oakum, and well pitched. The weight of the various beds of moorstone was calculated to be 270 tons, and served to act as ballast to keep steady this work of ship-carpentry. All the windows, shutters, and doors, were composed of double plank, crossed and clamped together; they shut into a rabbet, so that there was no crevice left the sea-water to penetrate.

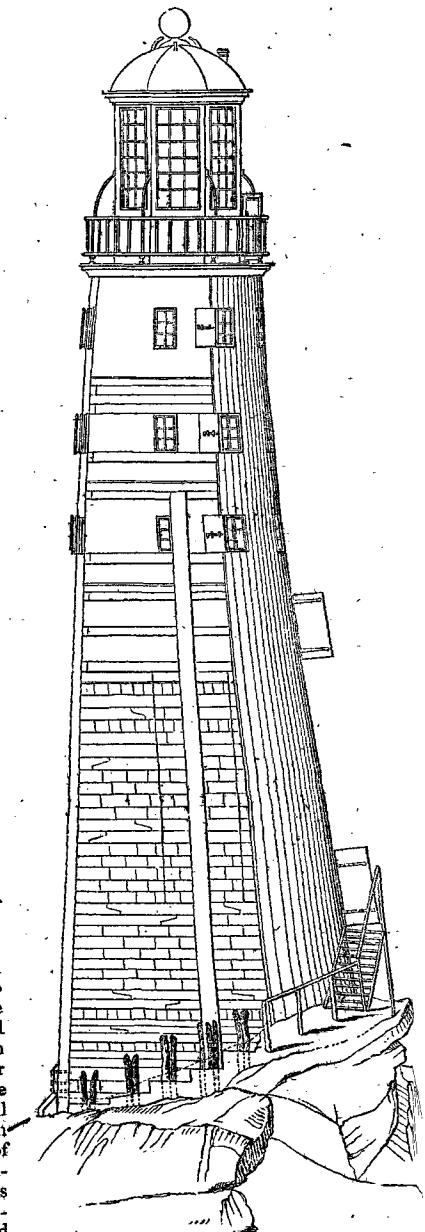


Fig. 372. RUDYERD'S LIGHTHOUSE.

This building, finished in the year 1709, was repaired at various times, and answered perfectly its purpose; but in December, 1755, it was totally destroyed by fire. The Earl of Macclesfield, then President of the Royal Society, being requested by the proprietors to recommend an engineer to reconstruct it, named Mr. John Smeaton, a philosophical instrument maker, as a man capable of executing the work; he was at that time in the north of England, but upon being made acquainted with his nomination, waited upon the proprietors, and having received their instructions, commenced his designs, though he admits that he was a total stranger to such structures. Smeaton has, however, informed us that he reflected much, previously to making his design, upon the several structures that had occupied the rock, and that he had a wish to retain as much of Rudyerd's as was consistent with the different nature of the material he had in view; and he observes further, "It appeared most evidently that had it not been for the moorstone courses, inlaid with the frame of the building, and acting therein like the ballast of the ship, it had long ago been overset, notwithstanding all the branches and iron work contrived to retain it; and that in reality the violent agitation, rocking, or vibration, which the late building was subject to, must have been owing to the narrowness of the base on which it rested, and which the quantity of vibration it had been constantly subject to, had rendered, in regard to its seat, in some degree rounding, like the rockers of a cradle. It seemed, therefore, a primary point of improvement to procure, if possible, an enlargement of the base; it also seemed desirable to adhere strictly to the conical form, where the necessary consequence would be, that the diameter of every part being proportionably increased by an enlargement of the base, the action of the sea upon the building would be greater in the same proportion; but as the strength increases in proportion to the increased weight of the materials, the total absolute strength to resist the action of the sea would be greater by a proportional enlargement of every part, but would require a greater quantity of materials; on the other hand, if we could enlarge the base, and at the same time rather diminish than increase the size of the waist and upper works; as great strength and stiffness would arise from a larger base, accompanied with a less resistance to the acting power, though consisting of a less quantity of materials, as if a similar conical figure had been preserved. A stone edifice having been determined upon, the engineer gave to it the form of the waist or bole of a large spreading oak; and made a model, by roughly turning a piece of wood, with a small degree of tapering, and then fitting it to the oblique surface of another block, which resembled that of the Eddystone rock; and found that by arranging the several curves carefully, they could be firmly united, to form an efficient foundation. The model having given ample satisfaction, it was ordered that the works should be proceeded with.

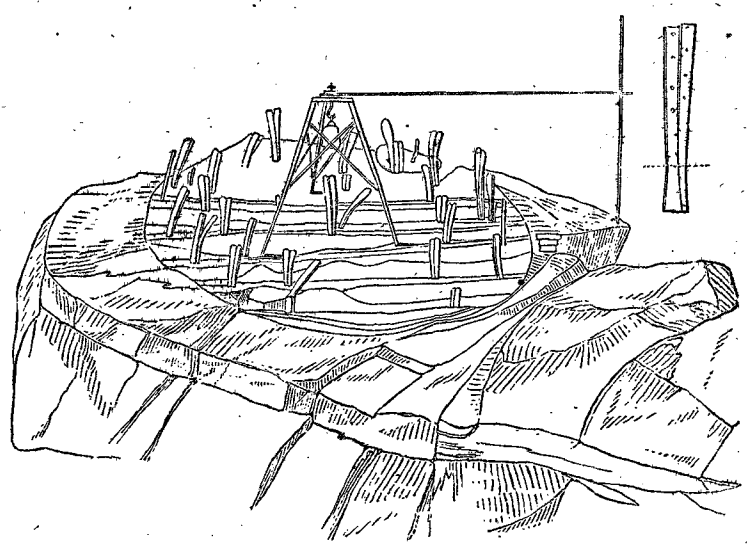


Fig. 373.

In the year 1757, all the necessary preparations being made, and the rock cut away for the reception of the first course, Mr. Smeaton, on the 12th of June, laid the first stone of the new lighthouse, which was of moorstone or granite, and weighed 2¼ tons. In the

first course there were altogether 4 stones, in the second 13, in the third 25, in the fourth 28, in the fifth 26, and in the sixth 26; these six courses brought the platform up

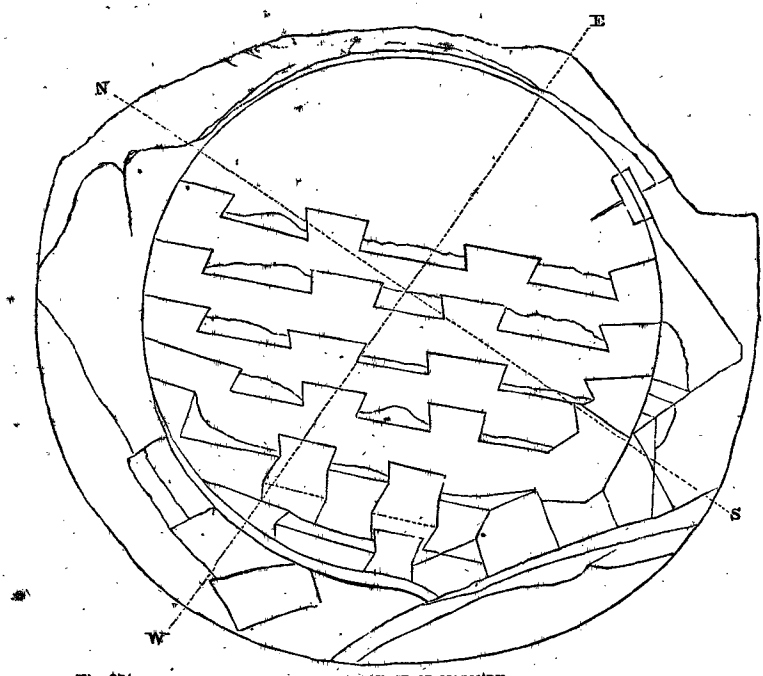


Fig. 374. FIRST COURSE OF MASONRY.

level with the top of the rock, and the laying of these 123 stones occupied 61 days; the whole were of moorstone, and cemented together with lime and puzzolana.

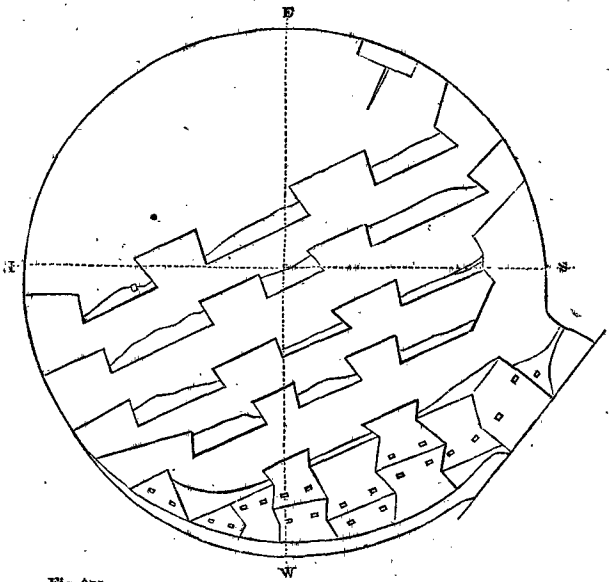


Fig. 375. SECOND COURSE OF MASONRY.

Each stone was separately worked on land, marked or numbered, and lines were drawn across the middle of each, tending to the centre as well as to the concentric circles,

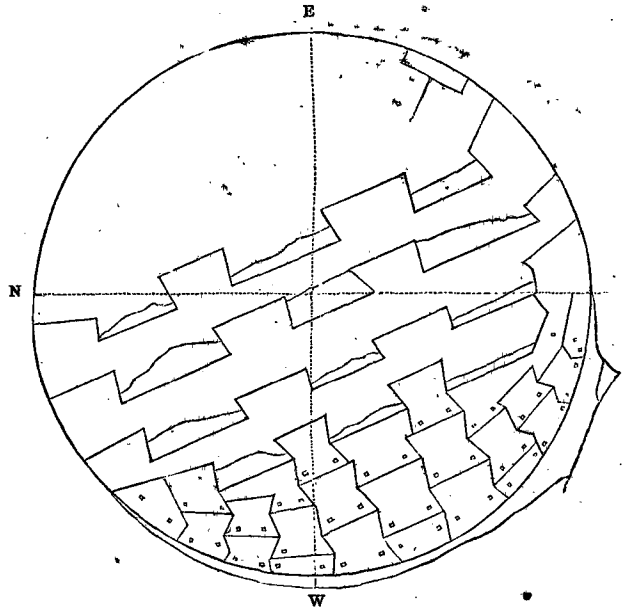


Fig. 376. THIRD COURSE.

to denote their position in the contrary direction; they also had a notch cut in the edges where they were to unite with those adjoining.

Each stone had cut, from the bottom to the top of the course, two grooves, 3 inches in

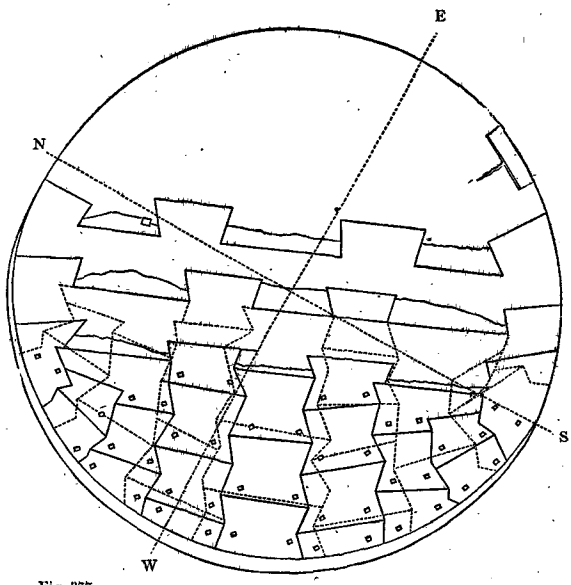


Fig. 377. FOURTH COURSE.

width, and 1 inch in depth, into which oak wedges, somewhat less than 3 inches in breadth, 1 inch thick at the head, nearly $\frac{3}{8}$ inch at the point, and 6 inches long, were introduced.

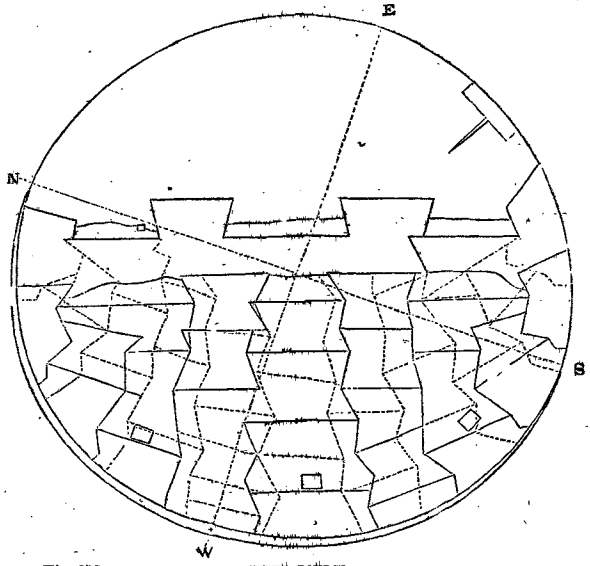


Fig. 378. FIFTH COURSE.

The mortar used was compounded of blue lias lime and puzzolana, in equal quantities, being prepared by beating it up in a strong wooden bucket made for the purpose, each

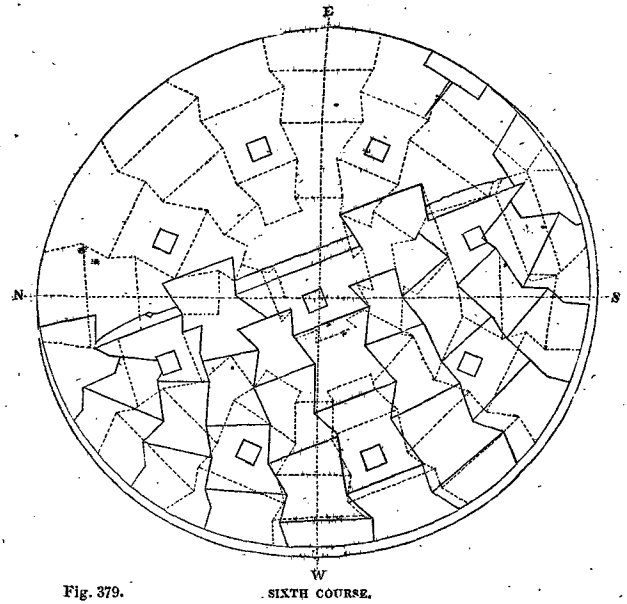


Fig. 379. SIXTH COURSE.

mortar beater having his own bucket, which he placed upon any level part of the work, and with a rammer or wooden pestle first beat the lime alone, using a quarter of a peck

at a time, to which, when formed with sea-water into a thin paste, he gradually added the puzzolana, and at the same time kept continually beating it.

When the mason had fitted the stone to its place, it was hoisted by a light movable triangle, furnished with a double tackle; then properly bedded, afterwards beat down with a heavy wooden maul, and levelled with a spirit level.

The carpenter then placed the oak wedges in the grooves prepared for them, one upon its head, and the other with its point downwards, so that the two wedges were head and point together; then, by means of an iron bar, $2\frac{1}{2}$ inches broad, $\frac{3}{4}$ inch thick, and $2\frac{1}{2}$ feet long they were driven down one wedge upon the other, very gently at first, so that the opposite pair of wedges being equally tightened, would equally resist each other, and the stone, therefore, keep its place; as the wood, when first inserted, was in a dry state, by its swelling with the moisture, it became tighter. To prevent the stones from being broken by driving these wedges, a couple of others were pitched at the top of each groove, the dormant wedge, or that with the point upward, being held in the hand, while the drift wedge, or that with its point downwards, was driven by the hammer; the whole that remained above the surface was then cut off with the saw; a couple of thin wedges were also moderately driven at the butt end of the stone, the tendency of which was to force it out of its dovetail; these were calculated to unite the mass, and prevent any violent agitation of the sea from displacing them.

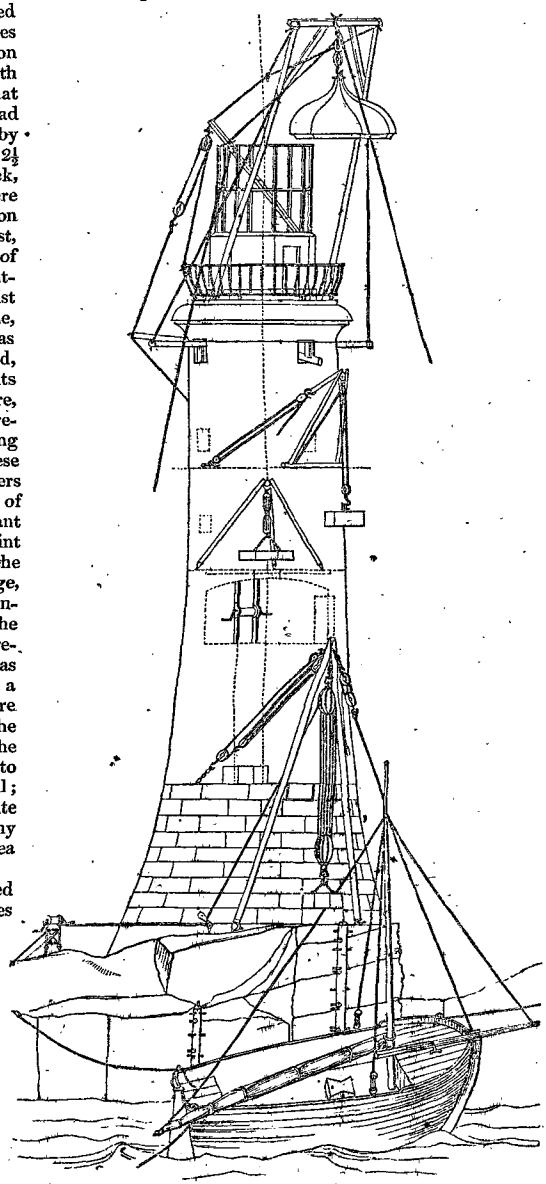


Fig. 380. EDDYSTONE LIGHTHOUSE.

The oak wedges served effectually to bind the stones together in their several courses; but to prevent their being lifted up before the mortar became hard, oak trenails were used. A couple of holes, $1\frac{3}{4}$ inches in diameter, were bored on shore, through the external or projecting end of each stone; after they were placed, and the wedges fixed, one of the tinners, or Cornish men, with a jumper continued the hole into the course below, and bored it about 8 or 9 inches in depth; but the lower hole was not so large in diameter as the one above by $\frac{1}{8}$ inch. The trenails, being nicely planed down to drive freely

through the upper hole, drove stiffly into the lower; after driving as far as possible, a saw-cut was made in the end to the depth of a couple of inches, into which a wedge, of $\frac{1}{8}$ inch

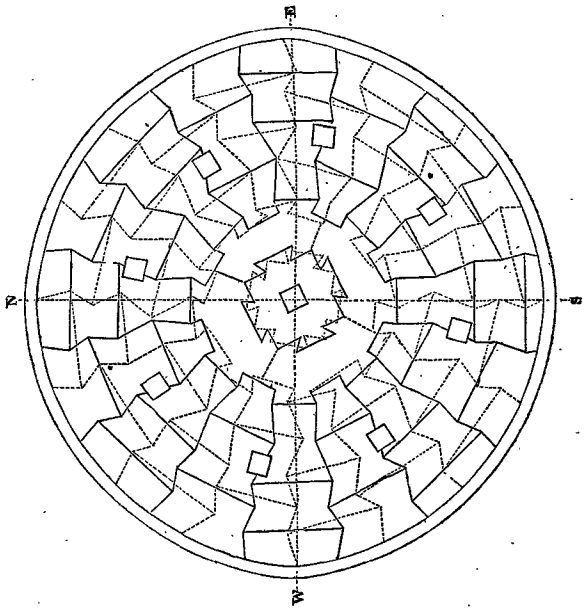


Fig. 381. SEVENTH COURSE.

in thickness at bottom, and double that at the square end, was driven. Each trenail was then cut off even with the top of the stone, and its upper end wedged cross and cross.

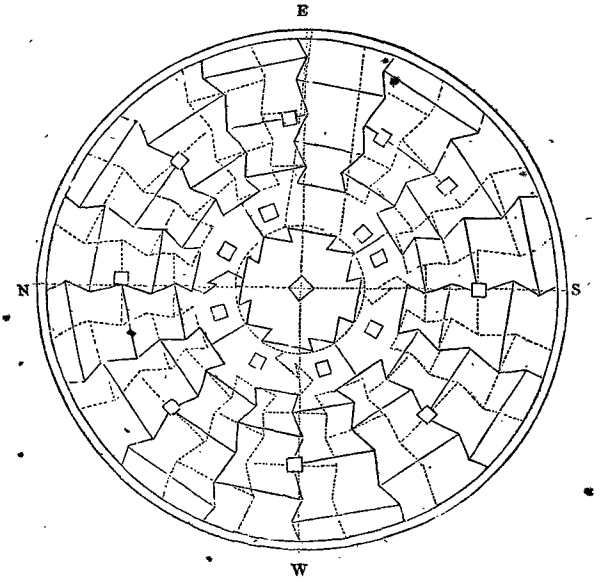


Fig. 382. FOURTEENTH COURSE.

There were two trenails to each stone; and it was found impossible, by ordinary means, to pull them asunder, or lift the stones after their introduction.

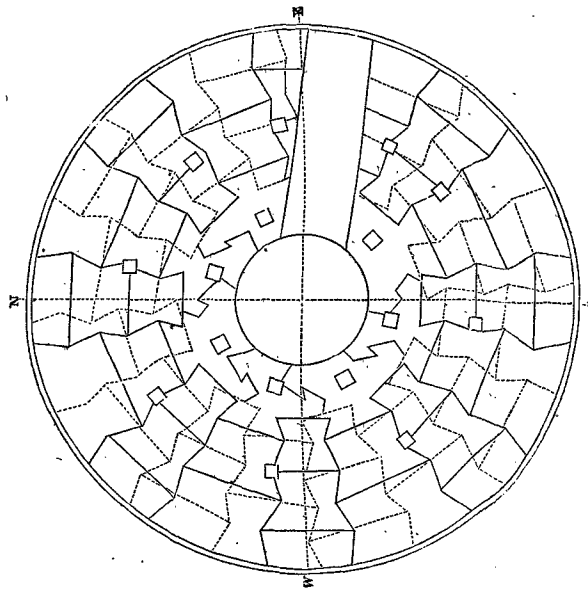


Fig. 383 FIFTEENTH COURSE.

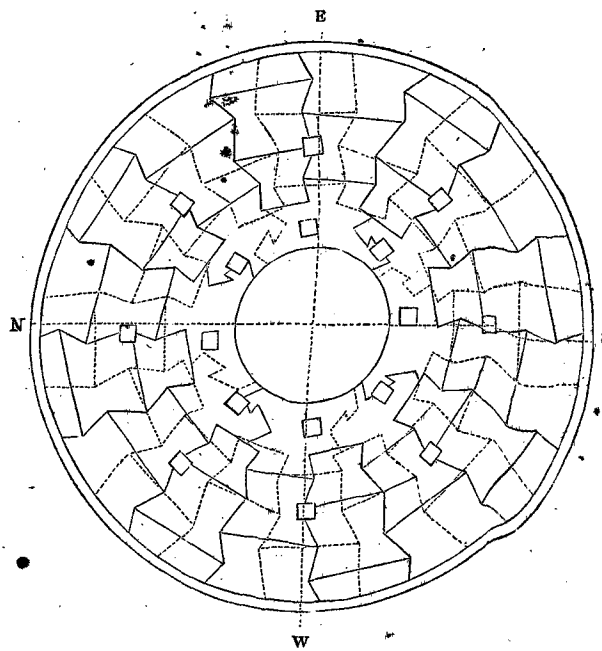


Fig. 384. EIGHTEENTH COURSE.

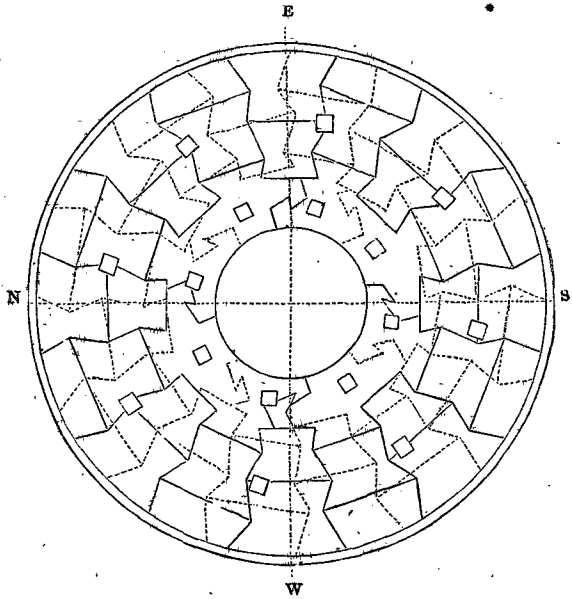


Fig. 385. TWENTY-THIRD COURSE.

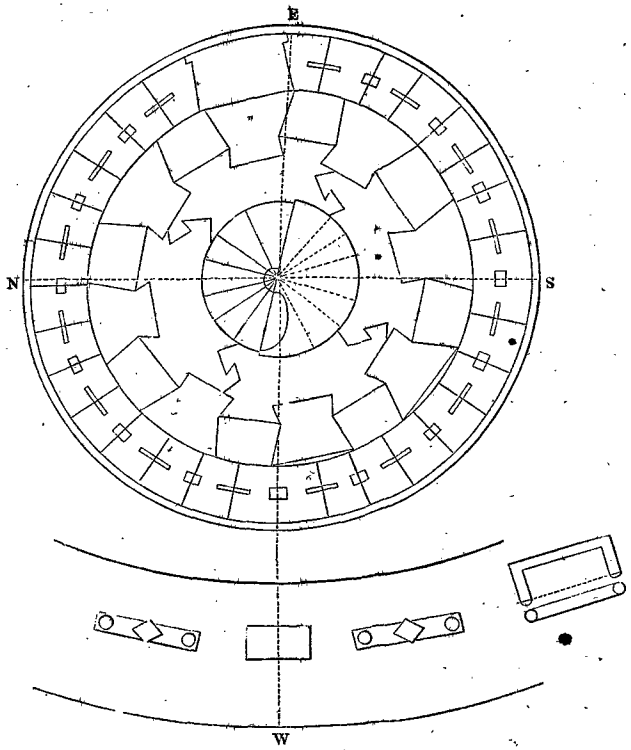


Fig. 386. TWENTY-FOURTH COURSE.

A quantity of liquid grout, made of the puzzolana mortar, was then poured into the joints by means of iron ladles.

Smeaton informs us, in his interesting account, of the pains he took to consider how the blocks of stone could be bonded to the rock and to one another, so that the whole and each individual piece should form but one mass, and be proof against the violence of the sea; and he plainly saw that every portion of the work was liable to be acted upon by storms.

" Cramping, as generally performed, amounts to no more than a bond upon the upper surface of a course of stone, without having any direct power to hold it down, in case of its being lifted upwards by an action greater than its own weight, as might be expected frequently to happen at the Eddystone, whenever the mortar of the ground bed it was set upon was washed out of the joint, or attacked by the sea, before it had time to harden; and though upright cramps, to confine the stones down to the course below, might in some degree answer the end, yet as this must be done to each individual stone, the quantity of iron, and the great trouble and loss of time that would necessarily attend this method, would in reality render it impracticable; for it appeared that Mr. Winstanley had found the fixing 12 great irons and Mr. Rudyerd 35 attended with such a consumption of time, (which arose in great measure from the difficulty of getting and keeping the holes dry, so as to admit of the pouring in of melted lead,) that any method which required still more in putting the work together upon the rock would in consequence inevitably, and to a very great degree, procrastinate the completion of the building. It therefore seemed of the utmost consequence to avoid this, even by any quantity of time and moderate expence that might be necessary for its performance on shore, provided it prevented hindrance of business upon the rock; because of time upon the rock there was likely to be a great scarcity, but on the shore a very sufficient plenty.

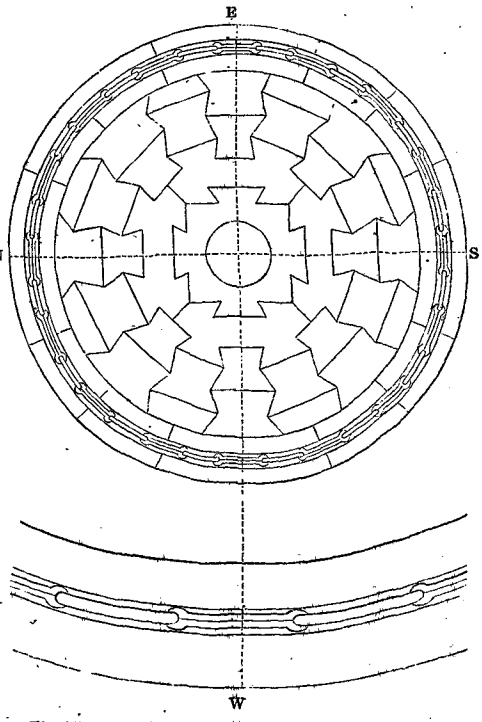


Fig. 387. TWENTY-NINTH COURSE.

" This made me turn my thoughts to what could be done in the way of *dovetailing*. In speaking, however, of this as a term of art, I must observe that it had been principally applied to works of carpentry; its application in the masonry way had been but very slight and sparing; for in regard to the small pieces of stone that had been let in with a double dovetail across the joint of larger pieces, and generally to save iron, it was a kind of work even more objectionable than cramping; for though it would not require melted lead, yet being only a superficial bond, and consisting of far more brittle materials than iron, it was not likely to answer our end at all. Somewhat more to my purpose, I had occasionally observed in many places in the streets of London, that in fixing the kerbs of the walking paths, the long pieces or stretchers were retained between two headers or bond pieces, whose heads, being cut dovetail-wise, adapted themselves to and confined in the stretchers; which expedient, though chiefly intended to save iron and lead, nevertheless appeared to me capable of more firmness than any superficial fastening could be, as the tie was as good at the bottom as at top, which was the very thing I wanted; and therefore if the tail of the header was made to have an adequate bond with the interior parts, the work would in itself be perfect. Something of this kind I also remember to have seen in Belidor's description of the stone floor of the great sluice at Cherbourgh" (this is shown in fig. 236.), " where the tails of the

upright headers are cut into dovetails, for their insertion into the mass of rough masonry below.

"From these beginnings, I was readily led to think, that if the blocks themselves were, both inside and out, all formed into large dovetails, they might be managed so as mutually to lock one another together, being primarily engrafted into the rock; and in the round and entire courses above the top of the rock they might all proceed from, and be locked to, one large centre stone.

"It is obvious that this method of dovetailing, while the slope of the rock was making good by cutting the steps formed by Mr. Rudyerd also into dovetails, it might be said that the foundation stones of every course were engrafted into, or rather rooted into the rock; which would not only keep all the stones in one course together, but prevent the courses themselves, as one stone, from moving or sliding upon each other. But after losing hold of the rock by getting above it, then, though every stone in the same course would be bonded in the strongest manner with every other, and might be considered as consisting of a single stone, which would weigh a considerable number of tons, and would be further retained to the floor below by the cement, so that, when completed, the sea would have no action upon it but edgeways; yet as a force, if sufficiently great, might move it, notwithstanding its weight and the small hold of the sea upon it, and break the cement, before time had given it that hardness which it might be expected to acquire afterwards, I had formed more expedients than one for fixing the courses to one another, so as absolutely to prevent their shifting."

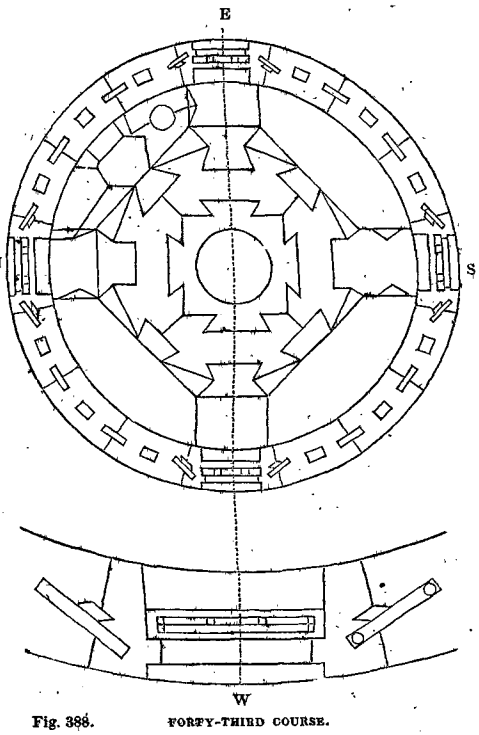


Fig. 388. FORTY-THIRD COURSE.

The six lower courses of stone, already described, were thus engrafted in dovetail recesses, cut out of the solid rock, and were therefore perfectly immovable from any force acting horizontally against them; as the work would not now have this natural advantage, it was necessary in the seventh course to adopt some means which should produce a similar effect; in the course number six, at the centre, a hole was cut, 1 foot square, and eight others, 1 foot square and 6 inches deep, were disposed at regular distances round the centre; into these were introduced cubes of marble, which were to act as joggles. A plug of strong hard marble, from the Plymouth rocks, 1 foot square and 22 inches in length, were set in mortar in the central cavity, and there fixed by wedges; this plug stood up 9 inches, and the centre stone of the seventh course, which had a square hole made in it, covered this plug, and, after being properly grouted, was held firmly together.

After this centre stone was fixed, the four that surrounded it were placed, united by as many dovetails, projecting from the four sides of the centre stone; these were secured by dovetailed wedges and grouted as before, and each held down by a couple of trenails. The whole formed a circular stone 10 feet in diameter, and weighing 7 tons, which was held by a centre plug and 12 trenails, the circumference of which admitted eight dovetailed recesses to be made in it, and to receive eight other stones of about 12 cwt. each, and in this manner did the work proceed until the whole of the solid part was complete. One plug in the middle, of a foot square, and each joggle of a foot cube, with the trenails, added to the strength of each course.

On the fourteenth course was set out the winding staircase and entrance doorway.

The building was carried up solid as high as there was any reason to suppose it would be exposed to the heavy stroke of the sea; that is, 35 feet 4 inches above its base, and 27 feet above the top of the rock, or common spring tide high water mark.

At this height it was reduced to 16 feet 8 inches in diameter, the rooms here occupying 12 feet 4 inches, and the walls 26 inches or 13 inches thick.

These were built with single blocks of granite or moorstone, and 16 were used in each course, cramped together with iron, and joggled at each joint. The joggles were made of sawn marble, 8 inches long, 4 inches broad, and 3 thick; each end of each block, therefore, occupies 4 inches in length, 4 inches in breadth, and $1\frac{1}{2}$ inch in the height of each joggle. To prevent any water or moisture passing through the upright joints, a groove was made in the end of each stone, into which an upright piece of stone, 6 inches broad and $2\frac{1}{2}$ inches thick, was slid into the cavity or groove prepared for it; these were mostly of Purbeck, selected for their firmness, and were run in with mortar; they also served to bond the work together. When in their places, the cramps were let in, which were flat bars of iron, 13 inches in length, 2 inches broad, and $\frac{5}{8}$ inch thick, and were turned down at each end about 3 inches in length, forming a cylinder $1\frac{1}{8}$ inch in diameter.

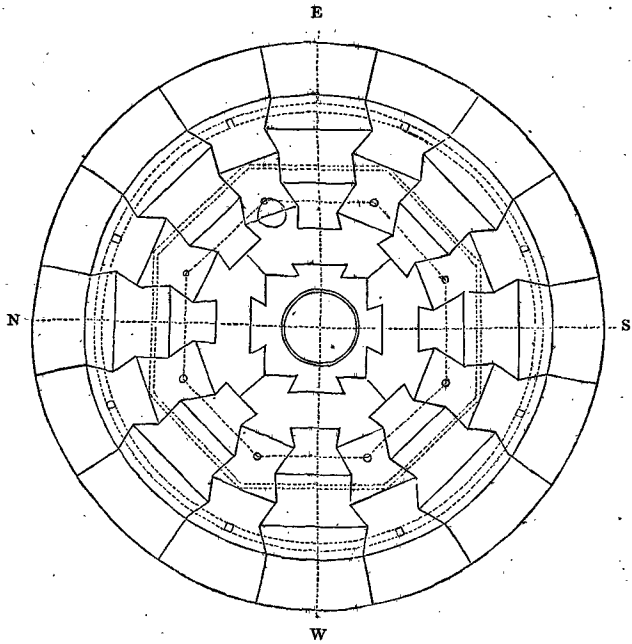


Fig. 389. FORTY-SIXTH COURSE.

The cramps being previously fitted to the stones, all that was necessary was to put each into a kettle of lead made red hot, and let it remain till it had acquired the same state. About a spoonful of oil was then poured into the cramp holes, and the cramp put into its place; the ebullition of the oil caused by the heat of the iron gave an oily surface to the whole cramp, as well as to the cavity of the stone; then the hot lead being poured in, the unctuous matter caused the metal to run into and occupy the most minute cavity, and thus defend the cramp from any action that might be produced from the salts of the sea.

At the twenty-eighth course was introduced the vaulted floor which formed the ceiling to the upper store-room; here was the first circular iron chain, which was lodged in a groove cut round the middle of the upper surface of this course.

The ordinary way of fixing the several courses by joggles and joint stones, and also the bonding them together by cramps, has been already described; by a reference to the section, it will be seen that each floor rests upon two courses, and that the circumference of the floors is not supported upon the sloping abutments of an arch, in lines tending towards the centre of the sphere, of which the underside of the floor was a portion, but upon a triple ledge carried round the two supporting courses: if each floor had been composed of a

single stone, lying upon the horizontal bearings furnished by the ledges, it would, while it remained entire, have no lateral pressure or tendency to thrust out the sides of the encompassing walls, and the several pieces of which the floors were composed might have the property of a whole stone; the centre stone was made large enough to admit of a man hole, with dovetails on its four sides, like those of the entire, solid, by means of which the others were connected with it, consequently the whole, like a single stone, rested upon the ledge, without any tendency to spread the walls, which was further provided against by an iron hoop or circular chain. Sir Christopher Wren, in the construction of the cupola of St. Paul's, had already adopted with success the same construction, and to this Smeaton refers for his model.

Each of the four floors had two endless chains, the bars of which are composed of links $1\frac{1}{4}$ inch square, and the grooves that received them were 4 inches in depth and width, and when placed each chain was run with 11 cwt. of lead.

	Ft.	*In.*
The height of the six foundation courses to the top of the rock -	8	$4\frac{3}{4}$
The height of the eight courses to the entry door - - -	12	$0\frac{1}{2}$
The height of the ten courses of the well hole to the store-room floor	15	$2\frac{1}{4}$
The height of the four rooms to the balcony floor - -	34	$4\frac{1}{2}$
Height of the main column, containing forty-six courses - -	70	0

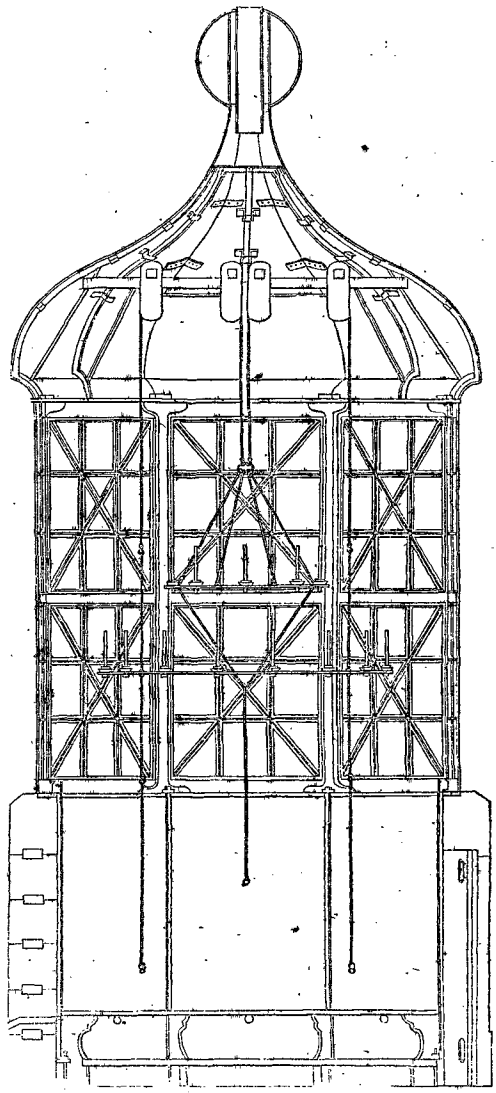


Fig. 390. LANTERN OF EDDYSTONE LIGHTHOUSE.

The lantern is formed mostly of copper; there are 16 frames with 9 panes each, and the balcony is covered with thick plates of lead; there were 16 sheets put together with strong ribbed joints; the whole of this work was very securely braced, and the copper funnel adapted to let out the smoke from the candles. A metal conductor, to guard against the effects of lightning, was added.

The lower diameter, immediately above the rock, is 25 feet, and the upper 15 feet, including the thickness of the walls; the height of the lantern is about 24 feet, and the diameter 9.

The building was completed in October, 1759; and upon the rock the workmen were employed 2674 hours; the number of pieces of stones used was 1493, independent of 75 large cubic joggles and centre plug-stones, 162 cubic joggles of 6 inches, used in the well-hole courses, 399 flat joggles in the courses of the rooms and lantern, 399 joint stones in ditto, 1800 oak trenails, $1\frac{3}{4}$ inch in diameter, used in the solid, 4570 pair of oak wedges for

steadying the stones of the solid, 8 large circular chains, two used at each vaulted floor, 221 strong iron cramps in the walls of the rooms and lantern, and 5 others in the foundation.

The whole time occupied between the first stroke upon the rock and leaving the light-house complete was 3 years, 9 weeks, and 3 days.

The stone employed was partly obtained from the neighbouring coasts, and from the Isle of Portland.

For the lower part of the building Smeaton contracted for 240 tons of moorstone or granite, which was considered to be preferable in point of duration, the price of which was 25*s.* per ton, roughed out according to the moulds, and 4*d.* per foot superficial for working the beds; this was the price delivered into the yard, and did not comprise the expense of carriage to the rock; the rest of the stone was brought from the Isle of Portland.

The lantern, as originally contrived by Smeaton, contained a chandelier 6 feet 4 inches in diameter, made for 16 candles and a smaller, 3 feet 4 inches in diameter, for 8; they were so disposed as to affect each other as little as possible by their heat.

In the year 1807 the Trinity House had the building thoroughly examined and some trifling repairs performed, removed the chandeliers and introduced in their place a reflector frame, fitted up with Argand burners and parabolic reflectors, formed of copper, covered with highly polished silver.

The *Granite* used for this work was obtained from the quarry, by splitting it with a number of wedges, applied to holes or notches, cut or pooled into the surface, made at a distance of about 4 inches apart, or according to the size required or the strength of the stone. These pool-holes were sunk with the point of a pick, in the way hard stones are usually quarried. The harder the granite, the more exactly it may be made to split to the size required; in many parts of Devonshire and Cornwall, the moorstone or granite is split into posts, 12 or 14 feet in length, and a scantling of 8 or 9 inches square, and the sides perfectly even.

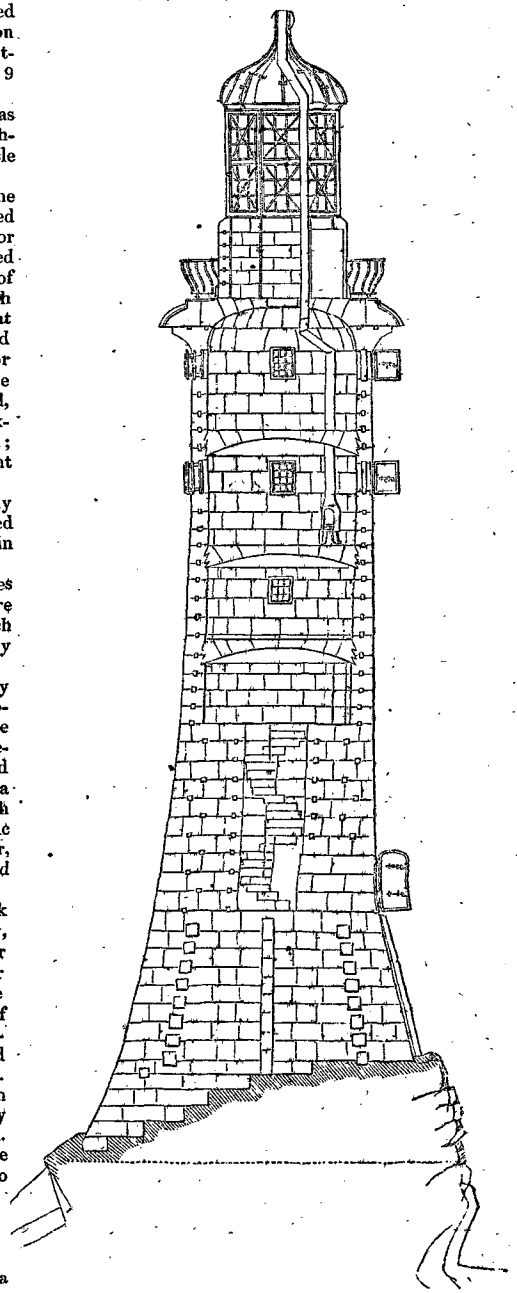


Fig. 391 SECTION OF EDDYSTONE LIGHTHOUSE.

At the Beare quarries, on the sea coast, near the south-east corner of Devonshire, Smeaton found the bed of freestone was of considerable thickness, and with so great a cover of earth upon it, that it was worked in underground cavities, the superincumbent earth being supported by pillars, formed of the detached parts of the stratum left standing. This calcareous stone resembled the Bath, but its bed was so thick, that blocks of any size might be drawn from it. It is very compact, free from fissures, and yet so soft that it can be cut with the common saw; after exposure it becomes hard, and in the buildings at Beare, where it is used, is covered with a mossy coating, and remains perfectly sound and free from decay.

Sand and limestone have each their peculiar lichen, and their respective qualities may be known by a careful examination of the plants produced upon their surfaces: granite and gneiss rocks are often found covered with Lecanora gelida, Lecidea petræa, Silacea, Lapicida, Verrucaria glaucina, &c. The rock crystal is known by its being the habitat of Lecanora fusco-atra var. dendricata. The rocks of porphyry exhibit on their surface the Lecidea pustulata and confluens, Parmelia ciliaris and furfuracea, and the Gyrophora deusta. The mica slate rocks are found covered with Cornicularia tristis and exilis, Gyrophora polyphylla, and of the variety frigida of Lecanora tartarea. The clay slate abounds with such lichens as Lecidea cupularis, Lecanora decipiens, &c. Sandstone near the sea is frequently found covered with the Ramalina scopulorum, Lecanora parella and atra. Limestone is furnished with the Lecidea immersa, Collema nigra, Verrucaria muralis, Urecolaria calcarea, and Thelotrema exanthematica. And any one acquainted with the characteristics of the several lichens may at once distinguish the variety of stone used in a building, where, in the course of time, they generally are covered with specimens of one kind or the other.

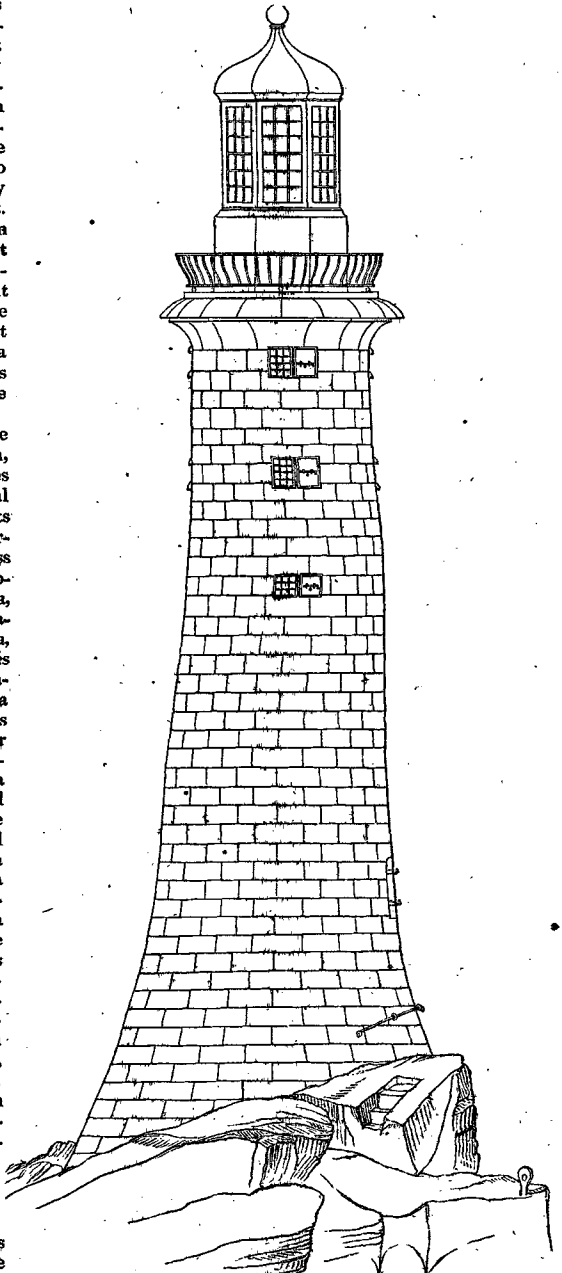


Fig. 392. ELEVATION OF EDDYSTONE LIGHTHOUSE.

The stone which Smeaton selected from the Isle of Portland was obtained where it lay in beds nearly parallel with the surface of the land, and is covered with a small quantity of earth.

There are several beds, varying in thickness from 2 to 4 feet and upwards: these are covered with a stratum called a cap, which is formed of shells of various kinds; some of them, as the Cornua Ammonis, are upwards of two feet in diameter; this capping is very hard, and is usually detached by blasting with gunpowder.

After this cap has been removed, the quarry-men proceed to cross-cut the large flats, which are laid bare with wedges, and split off the Portland, not in a very even manner, but in masses, the quarry-men, with a tool called a kevel, which is at one end a hammer and at the other an axe, whose edge is short and narrow, like a pick, reduce it to something like a cube, or regular shape. The face of the kevel is not at the hammer end quite flat, but a little hollowed out, which gives rather a sharp edge to two of its opposite sides, which are parallel to the handle; and by this means it is made to bite more keenly upon the stone, and to bring off a spawl or large shivers. The edge at the pick end is about half an inch in breadth.

Dartmouth Harbour is not only beautifully situated, but very safe for vessels, and capacious enough to hold 500 sail. It is defended by a fort, situated where the ancient castle stood.

The Dart is navigable to Totness, where are numerous manufactories.

Exmouth, at the mouth of the Exe, is situated near the shore, where the cliffs open as it were to receive it. It is sheltered from the north-east and south-east winds by lofty hills; this was the birth-place of Sir Walter Raleigh, who was the author of the History of the World, as well as its greatest navigator.

Sidmouth was formerly a good sea-port, where the small river Sid flows toward the ocean and loses itself among the pebbles on the beach, in consequence of the alluvium with which the harbour is almost choked up.

Axmouth, on the river of that name, is another small port, monthly resorted to by fishermen.

Lyme Regis, situated on the river Lyme, near the west bay, in a cavity between two rocky hills, has a spacious quay, and round the harbour are several forts for its defence; the chief is called the *Cobb*, which is very ancient, and composed of fragments of rock, in huge masses piled together; this fabric is of the greatest importance on this coast, as there is between Start Point and the Portland Road no other shelter for shipping. The Cobb, distant about $\frac{1}{4}$ mile from the town, is in the shape of a half moon, with a bar in the middle of the concave part. The stones are not cut or bedded in cement, and the surge plays in and out through the interstices. When a reparation is requisite, the new stone obtained on the coast, of as large a size as possible, is floated by means of casks chained together, with a man mounted on one to steer them. Such is the description given by Lord Keeper Guildford in his time, and reported in North's life of that nobleman.

This is a very early example of a breakwater formed with *pierre perdu*.

Weymouth is situated within a fine bay, admirably protected by lofty hills on all sides. Leland observes, "that the tounlet of Waymouth, lyeth strait agayn Milton (Melcombe) on the other side of the haven, and at this place the haven is but a small brede; and the trajectus is by a bote, or a rope bent over the haven, so that in the ferry bote they use no oars." He mentions also, that there is "a trajectus into Portland, by a long causey of pebble and sand."

Poole, on the north side of the bay, stands on a peninsula, connected by a narrow isthmus with the main land, which is $\frac{3}{4}$ mile long, and $\frac{1}{4}$ mile in breadth. This is surrounded by a spacious quay.

At the east end of the bay, about 3 miles north-west of Studland, is the Isle of Brownsea, $1\frac{1}{2}$ in length, and $\frac{3}{4}$ in breadth.

Christchurch Harbour, Hampshire, is situated at the bottom of a deep bay, lying between the Isles of Wight and Purbeck, and at the mouths of the Avon and Stour. These rivers form in their passage to the sea an inland basin, which is defended from all winds; in former times the mouth of this harbour was much more extensive, as the heads of land which bounded it, being formed of loose sand and iron-stone, have been, to a very considerable extent, washed away; much of this sand now forms a range of hommacks or sand hills, extending from Christchurch Head north-eastward, to the south point that now constitutes the harbour's mouth; here a bank has been thrown up, which separates the basin of Christchurch from the sea; the sands have thus driven the mouth of the river to the north-east.

The two rivers, which drain a considerable track of country in time of floods, pour down a quantity of water and keep the channel open, but in consequence of the small rise of the tides, which is not more than from 5 to 7 feet spring tides, and from 4 to 6 at neaps, it is not very practicable to obtain a very great depth of water in the harbour, and the increase of the sands, their constant motion, and the flatness of the bottom of the bay, also contribute to prevent any great improvement being carried out.

Christchurch quay lies 2 miles up the river from the harbour's mouth, about a furlong from which, in the reign of Charles II., was carried out a pier or jetty in a straight line,

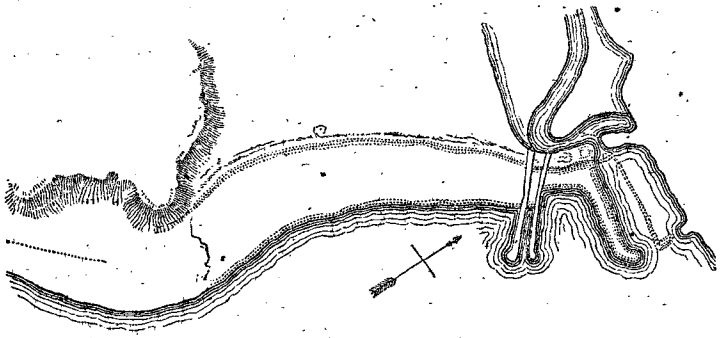


Fig. 393.

formed of round lumps of iron-stone, its direction being south-east, and its extent, beyond high water mark, 770 feet; its top gradually declines from the shore towards the sea, the whole being uncovered at low water, but at high water the greatest part is covered.

This pier was intended to secure a better passage to the harbour, and was made by cutting through the hommacks, to let the water out, and to direct its course to the south-west side of the pier.

Smeaton, in the year 1764, reported upon the condition of the harbour, and designed and estimated for an additional pier.

Southampton has of late years risen into considerable importance, from its regular communications with the coasts of France, Spain, and Portugal; it ranks among those towns which have a Roman origin, and was of great extent when the Saxon kings resided at Winchester; the walls and gates which remain are probably some of the constructions of that time. In Domesday Book, Southampton or Huntune is styled a burgh.

The Test, Anton, and Ilchin, here unite and form the Southwater, in which vessels of 1500 tons may sail.

Spacious and commodious docks have been formed since the railway has been completed, which opens a direct communication with the metropolis.

Portsmouth and Gosport had their origin, it is supposed, by the retiring of the sea; according to Camden, Portchester on this account was deserted for the Isle of Portsea; Edward IV. improved its fortifications, and increased the size of its port, and Leland notices having seen "in a great dok for shippes, in which lyeth part of the rybbes of the Henry Grace de Dieu, one of the biggest shippes that hath been made in *hominum memoria*."

The dock-yard and gun-wharf on the side of Portsea are very extensive, and contain all that a navy can require; storehouses, residences for the officers, anchor manufactories, docks, basins, jetty heads, rigging houses, &c. &c., where first-rate ships of war are constructed and refitted with an extraordinary expedition. In time of war upwards of 5000 artificers were employed here, and the activity of the whole establishment had nowhere its parallel.

Barracks, magazines, forts, mills, victualling yards, and other extensive establishments, surround this important depot.

Government has been furnished with a most complete survey of this harbour and its various lakes by naval officers, and it appears that the soundings entirely over are nearly the same as they were sixty years ago. The bar, off the south sea landmarks, is also unchanged in its dimensions, and is composed of flint, chalk, and gravel; this concrete could be easily removed, and without very great expense.

Little Hampton is formed by the channel of the Arun, which flows into the sea between two piers, composed of piles with an extension of Dicker work.

The depth of water in the entrance between the piers is 2 or 3 feet below the level of high water, but a bar extends outside the Dicker work across the mouth, which rises about 2 feet above the general surface, and is left dry at low water.

The lift of average spring tides is about 16 feet, and of neaps 11 feet.

The larger vessels which enter usually remain near the river's mouth, but a vessel of 13 feet draught, when she has passed the bar, can proceed to Arundel Bridge, a distance of 6 miles, the bottom continuing of an uniform level throughout that extent.

The tide flows 25 miles up the river, but the backwater is of little use to cleanse the mouth, from the narrowness of the channel and sluggishness of the stream.

Shoreham is at the mouth of the Adur, which formerly entered the sea nearly at right

angles with the line of coast, but it has, by the accumulation of the shingle, been diverted very considerably. This shingle now forms an embankment nearly 300 yards in width, and an artificial channel has been cut through it, about a mile from the town, the opening is preserved by wooden piers 218 feet apart, and which run in a south-west direction across the shingle into the sea. Within this entrance a third pier has been built out from the shore nearly across the harbour, for the purpose of diverting the waters on the ebb, from the eastern and western sides of the inlet, directly to the mouth.

The great body of water which thus ebbs and flows through the entrance serves to keep the channel open, and, though the width is so considerable, the stream runs between the pier heads at the rate of 5 or 6 miles an hour. The harbour mouth is nevertheless subject to a bar, which rises occasionally above the low water level, and shifts its position from 60 to 160 feet from the pier heads.

The lift of spring tides is about 15 feet, and neaps about 9 feet; the depth of water near the bar at high water is from 14 to 17 feet, according to the tides.

Newhaven is formed in the channel of the Ouse at its entrance into the sea, by wooden piers carried out in a southerly direction across the beach. The river is navigable as far as Lewes, and open to the flow and ebb of the tide 4 miles higher, or 12 miles altogether, and affords a powerful backwater for scouring the entrance.

The average rise of spring tide at the harbour's mouth is from 19 to 20 feet, and of neaps about 14 to 15 feet. The bar, however, is left dry at low water spring tides; but within the pier there is about 2 feet water at such time, and this depth continues uniform for a mile up the channel. The distance between the pier heads is 106 feet: on the western side of the harbour, the wooden pier, which extends about 250 yards, has been continued onwards by a stone embankment nearly $\frac{3}{4}$ mile in a straight line; and the bar, which formerly extended from the western side nearly across the mouth of the harbour, has been considerably reduced since the completion of this work; the eastern pier has been extended, and other improvements have been made by straightening and deepening the river above the town.

During flood tide and fine weather, the harbour is easy of access from the indraught and eddy tide which set towards the mouth; but from the rapidity of the stream during the ebb, it is not considered safe for a sailing vessel to enter, and the flag at the pier head is consequently lowered at high water.

The piers only extend to the line of low water on the beach, and this harbour, like others on the south coast, is greatly affected by the accumulation of beach and shingle, which cannot be effectually scoured or washed away by any means yet attempted. The latitude of Newhaven is 50° 48′ north, and its longitude 0° 5′ east of Greenwich; it lies directly in the course of vessels sailing up or down the channel. The original name of Newhaven was *Meeching*.

Cuxmere Haven, on the western side of Beachy Head, is an artificial harbour; the shingle beach crosses the entrance, and rises several feet above low water, and the interior of the haven is left dry at three quarters ebb.

Hastings has a small tidal harbour for the use of coasting vessels; here the coast runs, with little deviation, in a straight line nearly east by south, and is entirely exposed to the prevailing southerly and westerly winds. There is no natural breakwater, nor the facility of forming one; the shore is composed of shingle, and not above 4 fathoms of water at the distance of $\frac{3}{4}$ mile from the beach, which would give but a limited area of 12 feet at low water, in proportion to the size of the harbour, were piers to be carried out to such an extent.

In Jeakes's History of the Cinque Ports, we find that before the Conquest three only were incorporated, viz. Dover, Sandwich, and Romney; the Conqueror is supposed to have added Hastings and Hythe: the arms of the cinque ports are, per pale gules and azure, three demi lions, or, impaling azure, three semi ships argent. The chief prerogatives of these ports, in addition to their naval jurisdiction, are some ceremonies and honours at the coronation; the Lord Warden's power extends from Redcliff, near Seaford, to Shoe Beacon, near the Isle of Sheppey, and he has free warren over a considerable district in Kent. Hastings formerly had a pier, which was destroyed by a storm in the time of Elizabeth, who granted a contribution towards making a new harbour; the remains of this pier may be traced at low water, and it was called previous to its demolition the Strade, because vessels were wound up and let down the acclivity by a strong capstan, worked by three or four horses.

Boat-building is carried on to some extent, from the facility of obtaining fine oak timber, and the pleasure-boats constructed are said to be superior to all others.

Rye Harbour, one of the ancient cinque ports, stands on the edge of Sussex towards Kent, and is supposed by some to have been the Portus Novus of Ptolemy. The town was walled about in the reign of Edward III., and is now under the government of a mayor and jurats. As long as the tide was suffered to flow up the Rother, there was a good tide harbour; but a sluice placed some years ago about 6 miles above the town, and another at 3 miles, stopped the mud and sand brought in by the spring tides from running out, and

the whole became silted up. Before this, the harbour was sufficiently capacious and deep to shelter large vessels at low water; the sea being suffered at every tide to overflow what are now extensive marshes in the neighbourhood, by which means a vast body of water was collected, which, draining off, opened and maintained a spacious channel. In all similar situations, where the land has been walled in and converted to the purposes of agriculture, the tidal waters, from being confined and lessened in quantity, have lost their power of cleansing, and wherever there is not a sufficient quantity of land or flood waters to supply the purpose of scouring, the tendency must be to silt up. Besides this, a quantity of shingle or beach, derived probably from the constant wearing away of the chalk cliffs on this coast, was thrown up to the westward, which, being driven on the shore, was then carried by the currents in a direction nearly west-south-west and east-north-east; the wind at any point between south and south-west, now causes the sea to strike the shore obliquely, and to heap up greater quantities of beach, and drive it along the shore in the direction of east-north-east to the bottom of the bay or mouth of the harbour.

Thus, by the silting within, and the throwing up the shingle at the mouth, a surface of several hundred acres of land is formed, and the harbour has lost its value. As early as the year 1698, a report was drawn up, which states the harbour to be entirely lost, and in no condition to be preserved for any purpose of navigation. In the year 1719 the Admiralty Board, under whose direction the former report was made, sent down three competent gentlemen to make another survey, after which a new harbour was projected, which was partly carried into effect by Captain Perry, who had previously executed many considerable engineering works in Russia.

The mouth of the new harbour was put 2 miles westward of the old one, where the coast for several miles extends itself in a straight line, its entrance is nearly at right angles with the coast, and points south-south-east, or rather south-east by south.

In the year 1763, Mr. John Smeaton reported upon its then condition, and found that there was no increase of beach in the harbour; and at the foot of the beach, which is low water mark at neap tides, there was a fine firm sand, regularly inclined towards low water, which at spring tides was about 257 yards from the foot of the beach; and from thence inclined by very regular and gradual soundings, so as to make 20 feet at low water spring tides, and about 23 feet at low water neap tides, at the distance of 1 mile right out of the harbour's mouth; these soundings gradually increasing further out, where the bay formed excellent anchorage ground.

The tides here he found to have the greatest rise of any along this coast, for the common spring rose above low water mark 23 feet, and neap tides about 14 feet, viz. 17 feet above low water mark spring tides.

The direction of the tides was nearly along shore, and very gentle in consequence of their distance from the main channel tide, which was of great importance to the harbour.

The design of the new harbour was that of an extended canal; it had two stone piers projecting into the sea, as far as the foot of the beach, and the distance between them, which formed the mouth, was 120 feet; but a quantity of beach having collected at the back of the west head, it was prolonged by constructions in timber and stone, until it overlaid the east pier 210 feet.

From the pier head the harbour enlarged to a width of 200 feet, and at the distance of 730 yards within the pier is a large stone sluice. Between the pier head and the sluice, the harbour is formed into the arch of a circle of about 45°; so that no part of the mouth can be seen from the sluice, nor any part of the sluice from the mouth of the harbour.

The sluice was built of Portland stone, and consisted of two openings, one of 40 feet, shut by folding gates pointing to landward, the other had 30 feet clear water-way, shut by 5 draw-gates of 6 feet wide each.

By this contrivance the tide received into the canal above the sluice was shut in, and kept the vessels afloat during the whole time of tide, or was let off at low water by means of the draw-gates, for the purpose of scouring out the harbour. The length of the canal above the sluice is about ½ mile, and at the surface had a mean width of 150 feet, at the bottom 70 feet, which was the level of the sill of the sluice.

The canal, exclusive of the harbour, would contain about 200 sail of vessels, but not a sufficiency of water to answer all the purposes of keeping the outer harbour clean; it was constantly receiving deposits of mud from the Rother and its branches, which brought the waters from upwards of 100,000 acres of land.

When Smeaton examined the harbour, he found that the bottom of the channel, between the pier-heads, was about 6 feet above low water mark at spring tides, and about 8 feet above the sill of the sluice, and that in the course of a few years, as the scouring force was inefficient, the whole would be filled up, if some effectual means were not adopted to prevent it. He therefore advised that the Winchelsea channel should be widened and others made, the Rother dammed across, and new sluices built upon it, and that the tidal waters should be suffered to pass the great sluice into all these proposed new channels, and which were calculated to contain five times as much water as the original canal above the sluice.

In order that the drainage of the lands might in no way be injured, the tides were never to be shut in by the great sluice, so as to pen upon the aprons of any of the sluices for drainage, at a time when the levels were under water.

Smeaton's instructions were in part followed, and considerable sums of money were expended in endeavouring to arrest the movement of the beach from the west towards the east; the groins raised to stop it filled as soon as they were carried out, and the surplus beach was forced into the harbour's mouth.

The stone sluice falling to decay some years after was carried away by a river flood, when the inhabitants of Rye opposed its restoration; the absence of the impediment having given in one year 3 feet additional water in the harbour channel at the town quay.

The piers, wharf, and sluices, were in a few years completely silted up, when the masonry was dug out, and the stones sold. This harbour has been entirely ruined in consequence of excluding the tide, and depriving it of the benefits of its natural backwater; in shutting out the sea and preventing its flooding the lands which were originally covered, much valuable pasture has been gained and improved, but Rye, as a port of importance, has ceased to exist.

A wooden pier on piles has been carried out on the eastern side, and embankments have been thrown up on the western, leaving an entrance between of 160 feet in width.

The average rise of spring tides is about 17 feet, and during neap tides from 9 to 12 feet at the pier-heads, whilst the lift in the bay is 22 feet; at low water the harbour is left dry.

The depth of the channel up the river gradually decreases to the town, where there is 14 feet water at the top of spring tides, but during neaps seldom more than 9 feet.

The approach from the bay to the entrance of the harbour is very intricate and difficult, from the accumulation of sand and the winding course of the channel; the shingle, which extends on both sides of the harbour's mouth, accumulates with winds either from the westward or eastward of south, and forms banks, which, with the sand, block out the sea, and render the channel uncertain.

Folkestone.—This artificial harbour, formed by rubble stone piers, encloses an area of 14 acres; the western arm extends in a south-south-west direction, 140 yards across the beach, and is united with the main pier, which is carried in a straight line east and by south about 317 yards; a projecting pier has since been run out from the shore on the eastern side, towards the south-west, 236 yards, leaving an entrance of 123 feet in width, open to the east and by south.

Near the eastern extremity of the main pier, a groin has been constructed, which extends at right angles 130 feet seaward, intended to stop the accumulation of shingle, but in spite of this caution, it forms a bar at the harbour's mouth.

The rise of the spring tides is about 18 or 20 feet, and neaps 12 or 14 feet, but the harbour is entirely dry at low water, and the greater part of the interior is blocked up by a bank of shingle, which rises several feet above the level of high water, leaving only a narrow channel alongside the main pier.

At the north-western side, a small stream is pent up, for scouring the harbour at low water, which, with the assistance of manual labour, keeps the watercourse open, so as to allow vessels of 10 or 12 feet draught to come alongside the pier at high water.

Folkestone was the Lapis Populi of the Romans, the Folcestane of the Saxons, and the Fulchestan of Domesday Book; in the time of Leland it was "mervelusly sore wasted with the violence of the se," since whose time greater ravages have been committed on the whole extent of the coast. This town ranks among the Cinque Ports, and formerly was a place of considerable importance.

Dover Harbour, or *Portum Dubris*, is of great antiquity, deriving its name probably from the British word Dwfyrrha, which signifies a steep and hilly place; this by the Saxons was changed into Dorfa and Dofris, which in Domesday Book is made Dovere. The Romans had a town on the south side of the river which flows into this harbour, and the Watling Street took its departure from it, where Biggin Gate formerly stood. The straits of Dover have always been the medium of intercourse between this country and the continent, and no port in England is of more importance; it is worthy of remark, that before the pier was carried out there were no banks or shelves of beach to be seen, but all was clean sea between Archcliff Tower and Castle Cliff.

In ancient times the sea flowed over the greater part of the valley in which the town is now situated, and the harbour was considerably more inland, towards the north-east, than at present. Little is recorded of it until the time of Henry VII., when a round tower was built on the south-west side, to which vessels were moored to rings let into it, and as they rested secure here, it was called the Little Paradise. In the following reign the pier was commenced under the direction of Sir John Thompson, who held the living of St. James in the town of Dover; it was carried out on the south-west side of the bay, directly eastward into the sea, for a distance of 131 rods. It was formed of two rows of main piles, 26 feet in length, shod with iron, and driven into the main chalk; these were fastened together by

iron bolts and ties. The whole of the space between was filled in with large stones, some weighing 20 tons, which were freighted on rafts, supported by empty casks, from the neighbourhood of Folkestone; at this time more than 80,000*l.* were expended. Soon after the formation of this pier, a vast bar or shelf was formed across the harbour, by an immense

Fig. 394. DOVER HARBOUR.

quantity of beach being thrown up, which totally impeded the passage, there being only a small outlet left for the current of the water of the river. Every exertion was made to improve the entrance into this port, and it appears from a survey made about 1652, that it had 22 feet water at spring tides. Since that time various acts of parliament have been passed, and enormous sums of money expended; jetties have been erected towards the east, to prevent encroachments of the sea, and though the south-west winds still throw up large quantities of beach at the mouth of the harbour, they are partly dissipated by sluicing, the depth of water at spring tides varying from 18 to 20 feet, and at neaps about 14 feet.

This harbour has undergone many changes, the mouth at present being in a very different position to what it was formerly, which seems to have been occasioned by the constant motion of the beach or shingle, which is driven coastwise from west to east: the British Channel opens towards the west, and contracts eastward, so that the seas are much more violent and heavy from the south-western than from the south-eastern quarter. The violent storms, however, at south-east move the shingle westward, though the general prevalence is the other way, from west to east.

This shingle or beach is composed of flints produced by the destruction of the chalk cliffs, which when undermined are precipitated in large quantities into the sea; the chalk is dissolved, and the flints, rounded by attrition, form a constant succession of beach, an immense quantity of which is in continual motion along the coast, from west to east, part of which lodges and fills up every recess where it can be deposited and lie quiet.

This beach was the cause of the destruction of the old harbour, and it seems that the mouth has been shut up more than once, and has remained so for years; the mouth of the present harbour is nothing more than a cut through the beach to allow the land waters, pent up on the inside of the harbour, to have a passage, which in time was improved and defended by two piers composed of wooden piles, filled in with rough and heavy stones; after passing these, vessels arrive in a capacious harbour, defended from all winds, but having an open communication with the sea, the water flows and ebbs, and at low water spring tides the harbour is dry; it is divided by a dam or cross wall, in which, when Smeaton made his survey in 1769, was an opening 38 feet wide at top, and about 36 feet at bottom; in this was placed a large pair of gates pointing to landward, through which vessels at high water might pass from the outer to the inner harbour or basin, and be kept afloat.

Besides these great gates, there were two other openings in the cross wall, 12 feet wide, furnished with a pair of draw-gates.

The interior harbour was again divided by a second cross-wall with an opening of

20 feet for the passage of smaller vessels, which was also furnished with a pair of gates pointing to Landward; this cross-wall had three draw-gates, through which the water could pass for the purpose of scouring out the basin.

This upper reservoir is called the Pent, and here the fresh water river which springs from the chalk hills north of Dover empties itself, and makes its way through both sets of gates through all the three harbours, and lastly through the pier heads into the sea.

Smeaton observed that no arrangement could be more judicious, and that it corresponded with what had been done so effectually at Cherbourg, where immense sums of money had been expended, which was in a most perfect state before it was destroyed by the English.

When there are hard gales of wind and seas from the south-western quarter, a quantity of beach is brought round the western head, and lodges itself between the heads; the basin and pent are then filled, partly by taking in the sea water, and partly by fresh water afforded by the river, and there retained until low water.

The draw-gates of the sluices in the cross-wall are then opened with all expedition, and the body of water contained in the basin or pent, by making its way through the pier-heads, cuts down and removes the bar of the beach, which at the time of spring tides is done with great effect, and at two tides the mouth is effectually cleared.

When there are hard gales from the south-western quarter, and at the same time short or low neap tides, such a quantity of beach is accumulated, that it is with difficulty an entry can be made into the harbour.

The natural direction of the entry is east-south-east by the true meridian, and by the magnetic meridian, when Smeaton took his observations, it was south-east.

The western head was carried out in the natural direction of the harbour's entry, for about 30 feet in a line at or about south-south-east, when it suddenly turned to south-south-west, in which direction, after being carried 60 or 70 feet, it terminated by a salient angle, pointing to the same quarter. The line of direction of this flank of the pier being continued in an opposite direction, cut within the eastern pier-head about 60 feet, so that all the winds betwixt south-south-west and east-south-east occasioned the sea to strike obliquely, and, acting in the manner of a tunnel, bring the seas, when the wind is south or south-south-west, and the beach into the harbour's mouth; the south-eastern seas are so short, that they do not much affect it, but by the pier turning so much to the west, it greatly facilitates the beach, after it has passed round this salient point, to get along its flank, whose line of direction being overlapped by the eastern head is thereby caught and retained when the wind is more to the west than the south-south-west direction of this flank.

To lessen as much as possible the quantity of beach from getting round and lodging between the pier-heads, Smeaton recommended that the first mentioned line of head should be prolonged in its direction, south-south-east, until it was advanced sufficiently far to come into a south-south-west direction with the extremity of the east head, which would require an addition of about 90 feet. This additional work would form a sort of triangle, the base of which would be the south-west flank, whose projection forwards towards the south-east, in a line perpendicular to the base, would be but little above 60 feet further out.

By the elongation of these piers, it was not thought that the beach would be effectually prevented from entering the harbour's mouth, but that it would be lessened in quantity, and more readily removed.

The outer harbour at present contains $7\frac{1}{2}$ acres, the inner basin $6\frac{1}{4}$ acres, and the pent $1\frac{1}{2}$ acres; a wet dock of $1\frac{1}{2}$ acres opens into the western side of the outer harbour, which again communicates with a graving-dock.

The entrance between the pier-heads, now formed of stone and brick, faced with timber piles, is 110 feet in width, and opens to the south-south-east. The rise of average spring tides is from 18 to 19 feet, and of neaps from 12 to 13 feet; but the depth of high water in the harbour at spring tides is only 17 or 18 feet, in the basin from 16 to 17 feet, and about 3 feet less during neaps. The harbour therefore is left dry at low water.

Vessels on entering, when the south-westerly gales prevail, find great difficulty, as there is then a heavy sea at the harbour's mouth, from the bar of shingle which is thrown up, and which renders it inaccessible for several weeks together. In addition to three sluices or culverts connected with the inner basin by means of a pipe, there is in the western pier a brick reservoir, communicating by means of a tunnel 30 feet in width, and 16 high, with the inner basin and pent. From this reservoir five new sluices, 7 feet in diameter, lead to the extremity of the pier-head, and from the powerful volume of water thus discharged, and the impetus acquired by the proximity of the reservoir, it has been found sufficient, with the assistance of the sluices in the cross-wall between the basin and the outer harbour, to remove the shingle from the pier-head, and keep the channel clear to a level below the bottom of the harbour; but this shingle again returns or is thrown up with particular winds.

The tide flows from the south-west, at the rate of four miles per hour.

Sandwich Haven was a flourishing sea-port at the time the Isle of Thanet was surrounded with navigable water. Great changes have occurred by the silting up of the channels, which have been caused by the deposit of mud from the sea water, which is suspended in the water as long as it is agitated and kept in motion, but immediately it becomes at rest in an arm of the sea, or within shore, it subsides and is deposited.

Wherever the quantity and agitation of the water is too little, or the mud too great to be kept in motion, then its natural tendency is to rest. "Every creek, inlet, or bay," says Smeaton, "that has not a sufficiency of fresh water to keep it open, by being discharged through it, has a tendency to become land. While such a creek or bay remains deep, a quantity of tide water flowing in and out twice a day, tends to keep the mud in agitation and from settling; but as the tide of ebb is naturally weaker than the flood, the ebb will not carry out all that the flood has brought in; and when the deposition is so far advanced as to contract the breadth of the water, and render it to a certain degree shallow, the quantity of water flowing in and out being lessened, its power is weakened."

The natural means whereby an inlet is kept open is the discharge of a freshwater river through it, which opposing the influx of the tide, and adding to the force of its ebb, will always maintain a certain channel, in proportion to the quantity of land water that requires to be discharged. The tendency of nature is to contract the channel to such a size that the power of the stream can just maintain it, and in this state the wide extended arm of the sea, anciently flowing by Sandwich, and up the general valleys, as now called, seems to have been at the period that the new cut at Stonar was projected and executed. The Stour was never adequate to keep open so large an arm of the sea as that through which it flowed, and the force of its current was impaired by its meandering course. The declivity of its bed in time becoming less, and the drainage of the lands more imperfect, they turned the river through the narrow neck of land at Stonar, where in the space of $\frac{1}{8}$ of a mile there was a fall of a fathom.

The land floods, after heavy rains, are the clearers of the channels of rivers to sea, and this is chiefly effected when the tide is out, and most of all when they happen at the low ebb of a spring tide; at such a time more is done in a few hours than in months where the reflow is leisurely and moderate; one tears away all deposit with violence, the other grinds away but small particles of mud or sand, and a gentle reflow does not disturb a particle; but, on the contrary, if the preceding tide of flood has brought any silt with it, such a reflow will allow it to be deposited, and where nothing is done towards its removal in one tide, no number of repetitions will effect it. As long as the top waters are drawn off through the flood-gates of Stonar and the dribbling of the floods, and the ordinary current of the river left to go quietly round by Sandwich, no improvement can take place in the harbour.

John Smeaton, who made his report in the year 1789, observes fully upon the great injury sustained by the harbour, in consequence of the changes made for the sole purpose of draining the land, and improving its condition; he professes himself as great a friend to drainage as to navigation, and observes that the flooding of low grounds in the valleys of rivers is an advantage, provided it is done at suitable seasons of the year, and that the soil and manure brought down from the high lands and deposited on the surface of the low lands greatly improve their fertility; that the lands are not injured by the height or depth of water which remains upon them for a short time, but the contrary: the damage arises from the continuance of a small depth of water, which must be entirely removed from the soil before its fertilising powers can be called forth.

For the improvement of this harbour, he suggested that during the winter months, instead of drawing the gates when the water was just above the mark, after a dry season, they should remain shut for a few days, that the water might be permitted to overflow the meadows, and run again in its ancient course; and that as much of the top waters as could be made to pass Sandwich Bridge should be directed or allured that way in order that the whole channel of the Stour should be kept open.

A scouring power, acting by intervals, through Sandwich Harbour, together with the aid of the hedge-hog and spade in some particular places, might keep it clear.

The harbour has, however, grown both narrower and shallower, and the contraction of its section is a natural consequence of the loss of the force of the top waters of the land floods.

Whenever a fresh water river makes its way to the sea through the loose sand and silt that the sea has deposited, its course is continually varying; and when curved, the water, acting on the side, tends to increase its departure from a straight line; to alter this by the spade is a useless and endless work, and jetties are inefficient, as they will make fresh curves where there were none before.

Ramsgate Harbour.—As early as the reign of Edward VI. an attempt was made to form an harbour from Sandwich into the Downs, and traces of a canal may be seen between

Sandwich and Sandown Castle, which formed a part of the project. In the reign of Elizabeth, a commission was appointed to make a new survey; but nothing more was attempted until the year 1736, when M. Labelye, the engineer to Westminster Bridge, laid down a scheme for sheltering ships in the Downs, by means of a navigable canal and basin in the direction of the old cut, and by aid of sluices, which joined the river Stour.

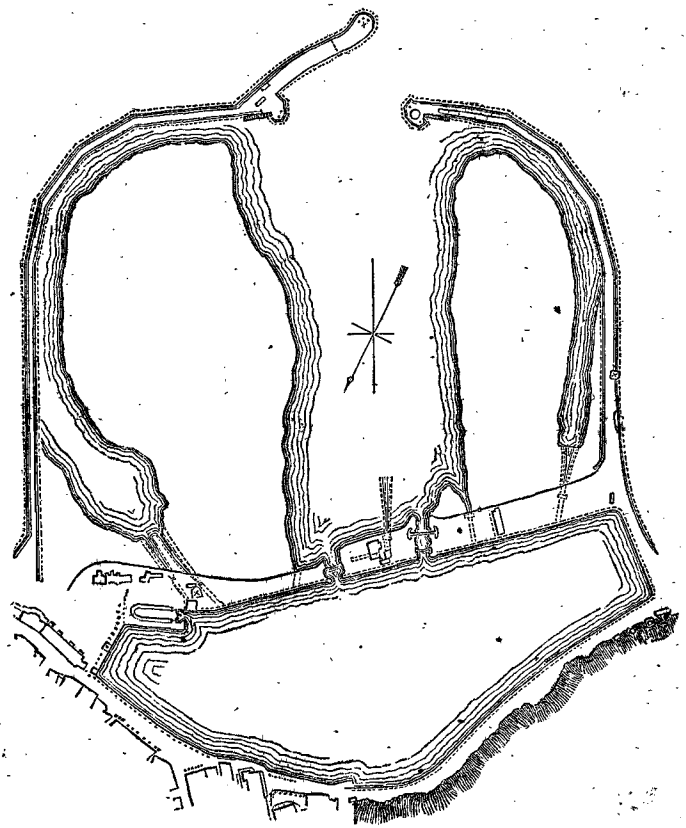


Fig. 395. RAMSGATE HARBOUR.

Parliament was afterwards applied to, and an order in consequence issued from the Admiralty by which five persons were named to report upon the means of making a better and more commodious harbour than the present haven of Sandwich; they proposed that two stone piers should be carried out, each 2096 feet in length from the shore, to 12 feet depth of water, at low water, and that a clear opening should be left between the heads of these piers of 300 feet, to narrow from that to 100 feet, and that the middle line should point south-south-east, half east by the compass, that is nearly south-east by the true meridian. The estimate for this work was 389,168*l.* 13*s.* 2*d.* exclusive of the value of the ground to be purchased.

This grand project, however, was never undertaken, and it was not until a violent storm, on the 16th December, 1748, when several vessels were wrecked, and a few found safety in the little harbour of Ramsgate, that attention was turned to this port, and soon after an act of parliament was passed, when Mr. Robins and Mr. Turner, engineers of Gosport, were appointed to mark out the site of Ramsgate harbour. It was found that in consequence of the pier constructed in 1715, having been lengthened, a bar had been cast up, which was about 2 feet 6 inches in thickness, and as this accumulation was the result of 34 years, it was reasonably presumed that when a greater depth of water was made by two piers instead of one, the filling up would be less considerable than before.

It was also observed that the sea-weed which drove in came from the westward; and that from the east there was a drift of large shingle, which it was thought would be of advantage to the new piers. When vessels broke loose from their anchors in the Downs, it was usually from three-quarter flood to one-quarter ebb, when the current of the tide is to the north, and north-east, which carried them right into the harbour at Ramsgate. The Goodwin Sands constitute the Downs as a roadway, and at low water these sands form a breakwater to all the easterly winds, and even at high water they are too shallow to admit the great seas to pass, without being broken and dispersed, and it is not till the tide turns to the north, which is at about three-quarter flood, that the combined force of wind and tide causes the ships to break from their moorings. The most advisable bearing for the entrance to the new harbour was then determined to be south-south-west; for if placed full south, the tide near high water would run so across it, that it would be difficult for vessels to get in; and if at south-west, there would be too great an indraught of sullage.

At the commencement of the works, Mr. Etheridge, who had been employed as foreman under Mr. King, the carpenter at Westminster Bridge, held the appointment of resident engineer; he laid the foundations of the piers in cases or caissoons, and showed the method of excavating a trench under water, and levelling it, which, being attended with certainty and dispatch, is the practice still followed; and the whole progressed under this engineer's superintendence until the works were ordered to be stopped; in the year 1755 a staircase called Jacob's Ladder was made from the top to the bottom of the cliff, which was the last work executed by Mr. Etheridge.

The east pier was, at this time, carried out 757 feet from the shore, and the west 849 feet.

In the year 1774, the works being incomplete, Mr. John Smeaton was called in to make a report, when he found that a large mass of silt, consisting partly of mud and chiefly of very fine sand, had been brought into the harbour by the tide; the tide water upon this part of the coast being charged with these matters whenever agitated by the wind, and accompanied by a quick flowing tide. This silty water, finding repose in the harbour, deposited its heavy matter, and the water only was taken back at the ebb tide; this is the tendency of all harbours, unless artificial methods are found to prevent it.

The most natural means to disperse it is by a fresh-water river, which continually tends towards the sea, and in time of floods carries with it whatever forms an obstruction to its course; where this means does not exist, such a harbour as that at Ramsgate must in course of time become dry land: when Smeaton made his report, there was found to be 268,700 cube yards of silt in the harbour; that the two barges with ten men each took out about 70 tons of silt per day; supposing 1 ton of silt to be 1 cube yard, it was calculated that they would be 12 years in clearing it out, even if there were no fresh accumulations.

The whole harbour contained 46 acres, and the external harbour, where the greatest quantity of silt was deposited, was about 30½ acres; and supposing that the whole was covered to the depth of $\frac{1}{10}$ inch per day, there would be 410 cube yards, which, at the rate of clearing 70 tons per day, would require a week. It was calculated, that all which had been deposited was the result of 12½ years, which was the time when the curves enclosing the harbour were raised to the level of half tide; the increase of silt was thought to be at least $\frac{1}{3}$ inch per week.

Smeaton, therefore, proposed to make use of an artificial backwater and sluices, and constructed a basin to take in the sea water, the tide having considerable rise and fall.

To prevent the basin itself from silting up, he advised that it should be divided into two parts, by a partition with a sluice or sluices capable of retaining the water in either while the other was empty, so that they might be used for alternately cleansing each other.

The harbour at Ramsgate was admirably suited for the execution of this plan; the bottom was composed of a hard chalk, and declined with an even fall towards the sea. The set of the tide runs across the harbour's mouth, so that when the sand was washed out by the artificial current, the natural current of the tides would carry it away, and effectually prevent any bar being formed.

Two basins of 4 acres each were proposed, and four draw-gates were to be made in the westernmost and five in the easternmost basin, the whole pointed in three different directions; two towards the curve of the western pier, four towards the harbour's mouth, and three towards the curve of the eastern piers. To give these sluices their full effect, it was suggested to construct a caissoon, shaped like the pier of a bridge, which being floated to its place, and there sunk in a proper direction, might be used to divert the current to the right or left, as was required.

Before this plan was put into execution, the committee of management ordered a lighter of 50 tons to be scuttled, 17 inches deep, and 14 inches broad on the starboard bar, and when placed at the end of the cross-wall to be filled with water. When the sluice was opened at low water, it ran out in a few minutes, and made a cavity in the sand some feet in depth and width; and afterwards, the water being confined in a channel guarded by

planks, a cavity was made in the sand when the water was discharged from the sluice, 7 feet wide and 6 feet deep; it was again tried, and the hole, after three discharges, was found to be 10 feet wide upon the surface of the sand, 6 feet deep to the chalk, and 3 feet wide upon the bed of the chalk, the channel being full 100 feet in length.

The piles were driven, and part planked, for the cross-wall to enclose the basin, in the year 1779, and soon after the sluices were completed; when all the men employed about the works applied themselves with handles to start the sluices; the spindles upon which the wheels were fixed broke upon the first attempt; but two of the sluices were raised at last by means of tackle blocks, when the force and power of the stream was so great, that it not only forced up the chalk to the depth of 6 or 7 feet, but carried away pieces weighing from 3 to 4 cwt. to a distance of 60 or 70 feet, and in its course cleared away the silt down to the chalk to low water mark, the stream continuing 200 or 300 feet beyond the harbour's mouth.

They could not raise more than two sluices at this time, but after some alteration this was rendered easy; the planking of the sluices was put to draw cross ways of the plank, which operating on a rough groove of stone caused considerable friction; when they were altered, and the spindles repaired and made of wrought-iron, the water was again pent up in the basin, and the whole discharged together, and it was found to have such power, that there was fear lest the cross wall should have been undermined; they therefore were obliged to construct proper aprons to prevent this.

The committee further reported, that since the cross wall had been built, the sea which before broke and spent itself upon the shore had now become so agitated that vessels were unsafe; that the sea mostly ranged along the western pier, and that the cross wall stopping and repelling the swell, it returned, not having any vent or outlet, and that this was the cause of the great disturbance and agitation complained of. To remedy this the committee then ordered that 200 or 300 feet of the cross wall should be taken down, and that from thence a wall should be built up towards the cliffs, and also that 80 or 100 feet of the timber pier should be taken away, beginning at the end of the cross wall, the opening to extend towards Jacob's Ladder; it was also recommended that another sluice should be made from the angle in the old pier, to scour the upper or northern angle of the east pier.

In the year 1781 the sixth sluice being completed, a new channel was dug through the sand, and a couple of barges were laid so as to direct the water through it; in a few minutes the bank was considerably diminished, and the water of this sluice flowed so high that it overtopped the conduit wall, and it was the general opinion, that by these means the harbour might be kept cleansed; in the channel under the east pier there was found 19 feet water at spring tide.

Mr. Smeaton afterwards gave a design for a new dock, and the first stone was laid July 31. 1784, but the walls were carried up without any timber floor; after this dock was built, the natural springs which rise in the chalk bed broke not only through the cement, but in many places issued with such violence as to break the paving-stones with which it was covered. It was then proposed to take up the whole of the pavement, and to do what had been done at Plymouth on a similar occasion,—lay down large blocks of stone 3 feet by 4, and 2 feet 6 inches deep, each stone weighing 1½ tons. After these blocks of Portland stone were all laid, and the dock shut in at the time of high water, the whole pavement was again hoisted, and 100 feet of the north wall lifted with it.

Mr. Smeaton was then requested to examine its state, and he reported to the committee, that on the day he arrived the tide rose 18 feet 4 inches upon the apron of the gates of the dock, but that before it had risen 2 feet it began to spring through several joints of the stone floor, which had been laid with the solid Portland blocks 2 feet 6 inches in thickness, in the form of an arch. As the height of the tide increased upon the apron, the leakage through the joints increased, so that when it was high water, there was a depth of 5 feet 3 inches water upon the floor.

The cause of these derangements was owing, he states, to the pressure of the water under the bottom, endeavouring like a vessel swimming in the water to buoy it upwards; and which, with 8 feet pressure, was calculated to produce that of 1000 tons over the entire area of the floor; and he was of opinion that had the wooden floor been introduced according to the original plan, it would have been subjected to the upright pressure only, and not to a lateral pressure as in stone arches. It was found that it was produced by the springs issuing from the area of the chalk on which the dock was founded, and that this would not have been the case had the soil been a compact clay or rock that would not have suffered the water to percolate through its pores.

Mr. Smeaton, who hitherto had been only occasionally consulted, was in the year 1788 appointed engineer to the harbour, and Mr. John Gwynn, who had already executed many works under him, resident surveyor. They immediately commenced rebuilding the dock, a timber floor was laid throughout, and an additional thickness given to the walls; here

Smeaton again turned his attention to the formation of a diving-bell, to be used in laying the foundations of a new advanced pier. Instead of the form of a bell, he used a square iron chest weighing $\frac{1}{2}$ ton; it was 4 feet 6 inches high and long, and 3 feet in width; and there was sufficient room for two men to work under it, who were supplied with a constant influx of fresh air, by a forcing air-pump placed in a boat upon the water's surface.

The advanced pier was built in caissoons, twelve of which being fixed, extending 120 feet, the masons commenced their work; this constituted about one-third of the intended length.

The timber breakwater, at the external angle of the east pier, being washed away, it was determined that its reconstruction should be of stone, and in the year 1790 this work was commenced.

In the year 1791, the dry dock built in the basin was tried for the first time, since it had been found necessary to introduce a timber floor, which was constructed in a new and peculiar manner, on account of the springs in the chalk rising so powerfully under it as to force up the stone floor, with which it had before been twice tried; the experiment showed that its construction was complete, and all that could be desired; and the advanced pier was very nearly finished.

The harbour now contains between its substantial stone piers an area of 42 acres, the piers extending 1310 feet into the sea. The inner basin is used as a wet dock, and contains a dry dock, where vessels of from 300 to 400 tons can be repaired.

The entrance to the outer harbour is 200 feet wide, and opens to the south-west. The average rise of spring-tides at the pier-heads is from 13 to 14 feet, and of neap tides 9 feet, giving to the entrance 19 feet at high water of spring-tides, and 16 of neaps.

The sluices for scouring the harbour are very powerful, and are constructed through the cross-wall of the inner basin; the water they discharge serves to keep open the channel, and the gullies which extend round the harbour at the foot of the piers, in certain portions of which, near the entrance, the depth increases to about 6 feet at low water. The mud in the middle of the harbour serves as grounding banks, and affords a soft bed, on which vessels entering can ground with safety. The opening of the gates of communication between the outer and inner harbour is 42 feet. In the outer harbour has been laid down one of Morton's patent slips, on which steam-vessels of too great beam to enter the graving-dock in the inner basin can be hauled up and repaired.

There is no natural breakwater to this tidal harbour, so essential for the purpose of scouring, nor does the line of cliff offer shelter against any winds but those which blow from off the land; it is, however, at present the best to be found on the south-eastern coast of England, and affords a place of refuge to vessels of considerable draught of water that run for protection at tide time.

The entire management of this harbour is vested by parliament in trustees.

Broadstairs had a wooden pier in the time of Henry VIII., erected for the security of the fishing boats; this pier is now about 100 yards in length, and extends from the northern side of a small bay. The entrance faces the south-west, and the harbour is much exposed to the sea, which is driven in by winds from the eastward.

At spring-tides there is about 16 feet water at the pier-head, and 10 feet at neaps; but the whole harbour is dry at low water, and during spring-tides nearly 100 yards outside the pier is left uncovered.

Margate had a pier at a very early period, near which was a small creek; the land on each side was, in the course of time, washed away by the sea, when it was necessary to protect the shores by additional piling and piers.

The harbour is situated in a small bay, between two extensive flats of chalk rocks, the Nayland on the west, and the Fulsam on the east, both of which are covered before high water. The artificial harbour is formed by a stone pier, which commences on the eastern side of the bay, and extends 800 feet to the westward, in an irregular course, leaving the entrance open to the north-west.

The rise of average spring-tides at the pier-head is about 13 feet, and that of neap tides 8 feet; but spring-tides ebb outside of the pier-head, and leave the harbour dry at low water.

A wooden jetty has been run out from the root of the pier, over the Fulsam rocks, to the distance of 1100 feet, for the convenience of passengers landing from the steam-packets at low water.

Douglas, in the Isle of Man, has an extensive bay on the eastern side, its width, between Douglas Head on the south, and Banks How, on the north, being $2\frac{1}{2}$ miles. Between the head and Quarry Point it is only 1 mile and 5 furlongs wide, and about 7 furlongs in depth, at right angles with this line, and which may properly be considered the bay. It is bounded by steep and perpendicular rocks of clay-slate, and has a depth of water at low spring-tides of from 2 to 5 fathoms.

The southern shores of the bay stretch as far as Douglas Head, on which the lighthouse

is placed. The town lies at the south-west extremity of the bay, at the mouth of a small river, which has a course of 10 miles, and which discharges itself into a smaller bay, separated from the greater by the Pollock Rocks, which ebb dry about 800 feet beyond high water mark, and are, upon an average, 15 feet above low water; there is another rocky island which is dry at low water, upon which there is a small tower of refuge for the mariners that may be driven upon it. St. Mary's, or the Connister Rock, is another shoal, between which and the Pollock the channel is not more than 300 feet in width, which is nearly dry at low water of extraordinary tides. The harbour is formed of a pier, which extends, from high to low water mark, a distance of 650 feet, terminated by a circular head and a lighthouse. Quay walls are continued from thence along both sides of the river for a distance of nearly 2000 feet, and the harbour comprised may be computed at 11 acres; it is dry at low water of spring-tides, and the bottom is composed of fine shingle.

The tides vary here considerably; the height of the springs occur two days after full and change of the moon at noon, when the tide rises from 19 to 20 feet, and extraordinary equinoctial tides rise 3 feet higher, and the neaps from 10 to 14 feet.

Port Patrick Harbour is the nearest port in Great Britain to Ireland, and is only 7 leagues from the opposite harbour of Donaghadee: when John Smeaton was called upon to report upon its condition, in 1770, he found it as nature had left it, with the addition only of a small platform for the convenience of the landing and shipping of passengers; it had, however, many advantages—it was easy of access, vessels of considerable size could remain afloat at low water, and they were protected from storms coming from seven-eighths of the whole compass, and had the other eighth, he observed, been as well guarded as the rest, the harbour would be complete.

The harbour is formed by two ledges of rocks running out almost parallel from the shore, so as to inclose between them a small bay of about 220 feet clear width, and about 550 feet in depth. The bottom is covered with a clean sand, and the soundings gradually increase from the shore to 20 feet at low water in the mouth of the bay, leaving from 9 to 10 feet at dead low water mark in the middle of the harbour.

As the Irish coast extends from the south-west to north-west, and being so very near, the swell, when the wind is right, is not considerable; from the north-west and north points, the fetch of the sea is not of great lengths, being to a certain degree land-locked by the Ila, Mull of Cantire, &c., &c.; and being well screened by the ledge of rocks, immediately on the north side of the harbour, which rise considerably above high water, no violence is experienced on that side. The land lies from north to south, so that nothing can happen from the eastern point; it is only from south to south-west inclusive that the harbour lies unprotected.

The rocks, which run out in the direction west by south on the south side of the harbour, point to the lighthouse of Donaghadee, and would, if higher, afford considerable shelter in all these winds; but the Irish Sea being open from these points, and the rocks being in a great measure covered at high water neap tides, and at three-fourth flood at spring tides, the seas break over them with so much violence in times of storms, that vessels lying there were beat against the sandy beach at the bottom of the bay, where they were retained by ropes as their only means of protection.

The vessels entering this port were, in consequence, obliged to be built very strong, and of so flat a construction that they would not sail except with wind on the beam or abaft. All the westerly winds prevent their sailing from Port Patrick to Donaghadee, and all the easterly winds from their returning, so that they cannot go and return unless the winds are southerly or northerly, and not then, if it were not from the strong current of the tides, which up and down this narrow channel change twice each way in 24 hours; so that sailing at a proper time of the tide, they are prevented by the current from sailing to leeward, but could vessels constructed upon proper principles be protected here, they would be enabled to turn to windward, and consequently make their passage good in all winds in moderate weather, an advantage that arises from the particular set of the tides.

For the improvement of this harbour, Smeaton proposed to run out a pier from the point of the rocks upon the mainland, crossing the gully between that point and the detached rocks called the South Ledge, and then follow their general direction. This pier was to be raised 6 feet above the high water of a spring tide, with a parapet 6 feet upon that; so that the whole being raised 12 feet above high water, vessels would be effectually screened from the south and south-westerly winds, as well as from those nearer the west.

The flow of the tides here was reckoned to be 15 feet at spring tides, and 12 feet at neap tides, but these varied with the winds.

When the work was advanced sufficiently to break off from that part intended for the interior harbour the great seas that roll in with the southerly and south-west winds, an additional pier was proposed, the position of which was nearly north-east, and this extended from the main pier 175 feet, leaving an opening into the interior harbour of 100 feet, between the pier head and the nearest point of the platform rocks, which served the effect

of a counter pier. Vessels then could at all times enter, and shelter be obtained for any of from 30 to 40 tons.

The width of this pier at the base is described to be 40 feet, and after fixing up leading marks from the first erected pier to the shore, stones were dropped in between them to form the foundation. These stones, which were rough masses of rock, were suspended by tackle in slings, and hooked or secured by a loop made of as many turns of rope yarn as would hold it, and by cutting the loop when the stone was in its proper position, it was dropped. After the outlines were established, the internal stones were tumbled into the area comprised between them.

The first stones dropped penetrated the sand, the second and third courses also disappeared in the same way, but after they had settled to a firm base, the rest of the construction was carried on by dropping the stones in a similar manner, taking care that the faces fell back on each side, and that the wall diminished in thickness gradually; and when any settlement occurred, or the stones were displaced by a storm, they were immediately set right and the injury repaired.

The diameter of the circular part of the head was 2 feet more than the common breadth of the pier, and the foundation was 43 feet.

The masonry of the upper parts was built with stones laid flat on their beds with mortar; the joints of the head of the pier radiated from a common centre, and every third course was securely cramped, and the centre stones retained by iron dogs. The cap or pier head had every stone cut like a dovetail, and was so put together that its strength was sufficient to resist the force of the seas opposed to it.

Belfast is situated on the river Laggan, near where it discharges itself into an inlet of the Irish Channel. The tides flow for a short distance up this river, but ebbs entirely out at low water, leaving a narrow and winding course through the sands for the river to flow out.

Spring tides rise in the roadstead 12 feet, and neaps 8, so that vessels which draw 10 feet water cannot reach the quays at neap tides, but are obliged to lighten their cargoes at Garmoyle.

Bay of Dublin. — On entering the nearest point of land, on the north and south are the promontory of Howth, and the island of Dalky, which are distant from each other 6¾ miles; from the line uniting these points, to the end of the lighthouse of the south wall, the distance is 3¾ miles; from the same line to Ringsend, 6¾ miles.

Towards the south Howth presents a bold ascent, interspersed with rocks and adorned with heaths of various colours; the mountains of Wicklow rise beyond in harmonious confusion, and the whole produces, on approaching this beautiful bay, great picturesque attractions.

On the north and west are two dangerous sand banks, produced by the channel of the Liffey, and which extend to the lighthouse on the south wall. The channel between them is not very wide, and the entrance is difficult, the depth of water at the recess of spring-tides not being more than 5 feet. Near the northern extreme line of the banks called the South Bull, a pier has been constructed, which is much admired; it commences at the village of Ringsend, and continues as far as the pigeon-house, a distance of 7938 feet. It is formed by two stone walls, filled in with gravel, and completed about 1756.

The Pigeon House, before the harbour at Howth was constructed, was the place where the packets received and landed passengers; and there is here an artificial basin, 900 feet in length, and 450 feet in breadth, which is nearly dry at low water.

Beyond the Pigeon House the pier is continued eastward 9816 feet, where it is terminated with a lighthouse; this division of the pier was originally timber, but in 1796 two parallel walls of hewn granite were built, without the aid of cement, and the intermediate space filled in with shingle and gravel; it is 32 feet broad at bottom, and tapers to 28 feet at top.

As it is merely a sea-wall, parapets have been dispensed with; the lighthouse at its eastern extremity, built in 1768, is a truncated cone, three stories in height, with a staircase on the outside, which leads to an octangular lantern; the whole is built of the mountain granite.

The pier secures the harbour from the sands of the South Bull, and with the quay walls forms one continued barrier, from the lighthouse on the east, to Barrack Bridge, at the opposite point of the compass, a distance of 6 miles.

The situation of Dublin Bay cannot, however, be considered favourable to the formation of a deep or commodious harbour; were it not for the discharge of the waters of the Liffey and Dodder, there would be scarcely accommodation for the smallest class of vessels.

The Liffey, being confined to a narrow course, the channel it cut through the sands was of very small width, regular in its depth, but constantly altering its direction.

Captain John Perry, who was employed to stop the breach made in the Thames wall at Dagenham, at the commencement of the last century, made some improvements in this harbour by forming a pier of drift work, damming up the waters of the two rivers before

mentioned, and constructing a stone sluice in the embankment, of sufficient width to admit vessels within at the high water of spring tides.

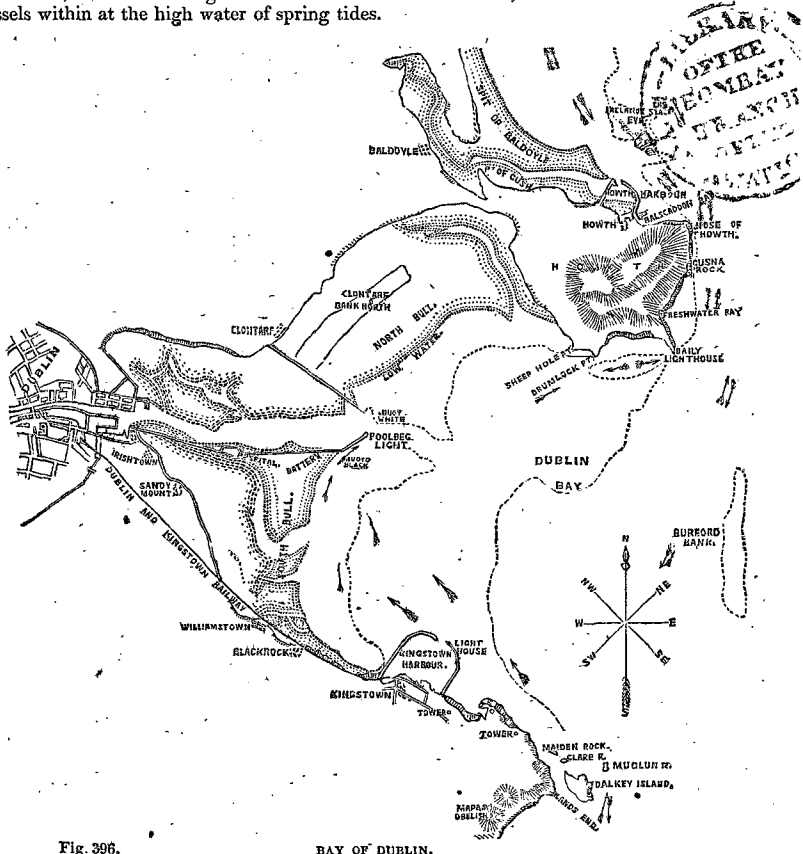


Fig. 396. BAY OF DUBLIN.

In the year 1711, when the soundings were taken, there was from 19 to 21 feet water on the bar at high water; and in the year 1800, Captain Bligh found that little alteration had taken place in either the soundings or set of the tides.

Howth.—The ancient name of this small port was Ben-hy-dair, or the Promontory of the Oaks, or, as some imagine, of birds; this is connected with the main land by a sandy isthmus, about ½ mile in width.

The new harbour is formed on the north side of the peninsula, in the sound, between the promontory and the island termed Ireland's Eye. From the northern shore of Howth, on the one side, and the south-east point of the island on the other, are two ledges of rock, which are ½ mile apart.

Between the north-west end of the island and the sands of Baldoyle there is a similar passage, and by these two passages the sound or harbour is entered.

Ireland's Eye is distant about a mile towards the north from the shore, and is little more than a mile in circuit.

In this harbour, a pier has been formed on the ridge projecting from the main land, 200 feet in width at the base, and 85 feet at high water mark; it is 38 feet in height, and runs 1503 feet from the shore, where it forms an obtuse angle with its first direction, and proceeds north-west for the distance of 990 feet, at the extremity of which stands the lighthouse.

On the west has been raised a pier 170 feet wide at the base, and 80 feet broad at high water mark; it is 36 feet in height, and runs 2020 feet on the north-east, to meet the return of the other, the entrance between being 300 feet in width, and the area inclosed not less than 52 acres.

The inside of the pier is faced with cut granite, and under low water, was built by

means of the diving-bell. The first stone was laid in 1807, and the whole was completed for the sum of 305,000*l.*, under the direction of the late Mr. Rennie.

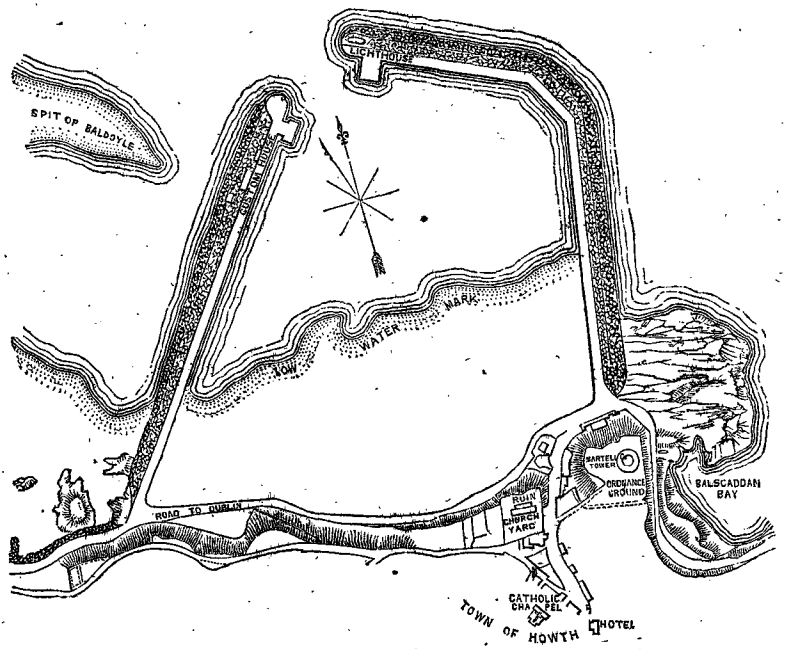


Fig. 397. HOWTH HARBOUR.

Kingstown, formerly called Dunleary, is distant from Dublin 5¼ miles; here is a small bay, naturally formed by an indentation of the coast, and from an early time there was a pier of rude construction, which afforded shelter to vessels under stress of weather.

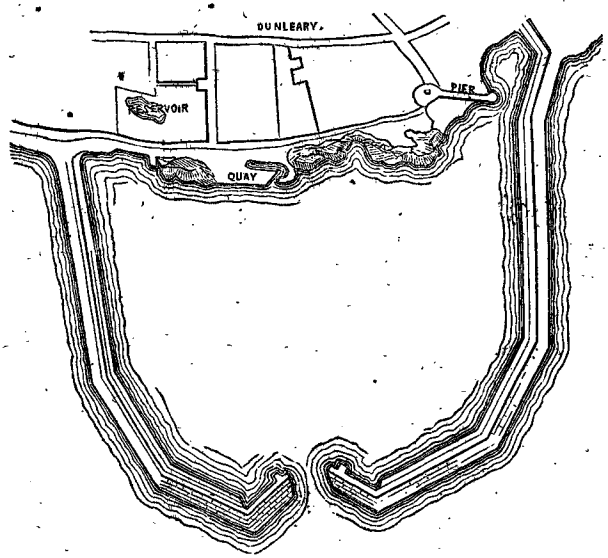


Fig. 398. KINGSTOWN HARBOUR.

The new pier is formed half a mile further to the east, or nearer to Dalkey, at the commencement of a rocky tract, called Codling Rocks, to the westward of which, within shelter of the pier, the bottom is of fine sand.

The first stone of the new pier was laid in 1817; it extends 2800 feet, and has four arms, the first running directly from the shore, to the distance of 1500 feet, in a north-east direction; the next continues north, the third north-west, and the fourth west, each 500 feet in length. The base of the pier is about 200 feet in breadth, terminating in a perpendicular face towards the harbour, and battering towards the sea; on the top runs a quay, 50 feet in width, which is protected by a parapet wall, 8 feet high. At the extremity is placed the lighthouse. The depth of water at the pier-head is 24 feet at the lowest springs, which at all times is sufficient to shelter large trading vessels and ships of war. The estimate for the completion of these works, as laid before Parliament, was 505,000*l.*

The Harbour of Cork, 8 miles from the city, is one of the most capacious and secure in the British empire. The outward entrance is barely half a league, but having passed a bank, called the Turbot, on which there is 30 feet water, the entrance narrows to half a mile. In this great basin lie the two islands of Spike and Halbowlin, placed as it were to form bulwarks against the winds and the ocean; so that vessels may lie in the harbour land-locked. Extensive barracks and a dockyard are formed on these islands, which are distant from Dublin about 125 miles.

Jersey Harbour.—St. Helliers, when Smeaton reported upon it in 1788, had a pier, which he denominated a *screen*, and he suggested some improvements, which have since been partially carried into effect; but he observed, "that no small harbour could be made quiet,

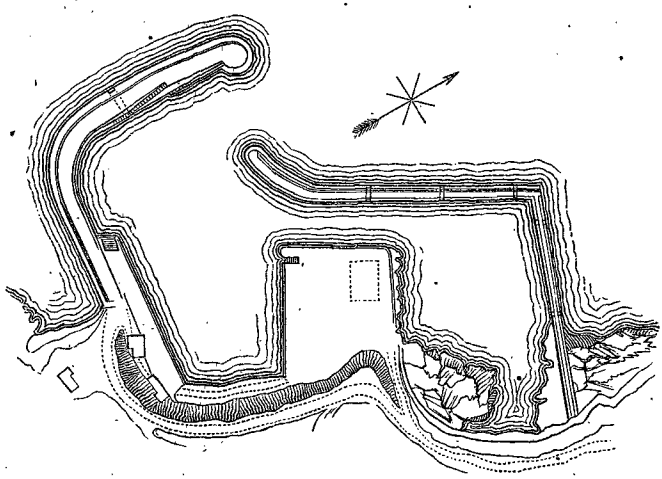


Fig. 399. JERSEY HARBOUR.

for the magnitude of the waves are supposed the same to all, and the necessary width of the mouth for a ship to enter the same: seas, then, that will inevitably sweep round the heads, will affect a smaller harbour more than a large one, though of similar constructions; for the effect of the waves in disturbing a harbour is greater in proportion as the lineal width of the mouth is to the whole area of the harbour: for this reason St. Helliers must always be defective. Another circumstance tends to render such a harbour unquiet, and that is, when they are bounded by walls. The waves of the sea follow the laws of the pendulum, which, when once set vibrating, would never cease if not stopped by friction and the resistance of the air. The same would happen to the libration of the water if there were nothing to stop it; for, meeting with walls and objects comparatively smooth, the waves are not destroyed, but reflected into another direction, and from that into another, till they are gradually dispelled by friction. The speediest way by which waves are destroyed (that is, by friction,) is by forming a surf, and breaking upon a sloping beach, sand, or rocks, in which the harbour of St. Helliers is defective."

The catch pier, suggested by this engineer, extended into the harbour 550 feet, and the spring-tides rise here upwards of 40 feet, but the neaps run very short.

There not being in the inner harbour any backwater to scour away the sand, it accumulates in large quantities, and Smeaton advised the making of arches through the pier, as was practised by the Romans, and which had the effect of disturbing the deposit, which was partly carried out to sea on the retreat of the tide.

St. Aubin's Harbour is also in the Island of Jersey, and upon it Mr. Smeaton also drew up a valuable report when he visited the last mentioned harbour. He observes: — "Experience having shown that the new pier of St. Aubin, called the Upper Pier, intended to bring up ships and vessels close to the town, for the convenience of fitting them out, loading and unloading, is, from its situation, liable to fill, from the great quantity of gravel which the sea washes in from the back of it, and that the depth of water is, from that

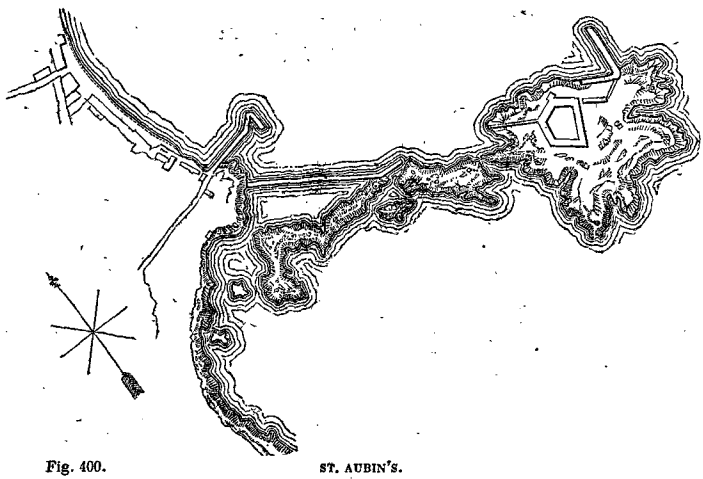


Fig. 400. ST. AUBIN'S.

action of the sea, diminishing more and more." And he further states, "that where a sloping shore is interrupted by the erection of a wall, as a wall has not that tendency to spend and destroy the waves of the sea that a sloping shore constantly has; wherever walls are erected in the confines of a harbour, it is rendered, in a degree, less tranquil by this means."

The reason of the gravel accumulating at this upper pier seems to have arisen from the west end of the Island of Jersey lying so exposed to the Atlantic, without any land to shelter it; the south-westerly winds, therefore, drove forward the gravel, brought coastwise, towards the bottom of St. Aubin's Bay, where it met the upper pier.

Smeaton suggested that a pier should be carried out in a north-easterly direction, which, flanking the current with a considerable obliquity, might prevent this accumulation.

Having now enumerated most of the harbours of Great Britain, upon which vast sums have been expended, it is a subject of regret that few answer the purpose of sheltering vessels at all times from the heavy gales our 2000 miles of coast are subject to.

Milford Haven, Portsmouth, Plymouth, Cork, and a few others, may be entered at all times of the tide, whilst the harbours on the eastern shores in particular are nearly all choked up, and incapable of receiving large vessels, excepting at the highest state of the tide. A good harbour requires a depth of water which will permit the largest vessels at all times to enter, and that it should be easy of access, with quay and piers, at which ships could load and unload their cargoes without inconvenience.

Most of our harbours being formed by piers, not sufficiently carried out from the main land, are consequently dry at low water, have bars at their entrances, and do not afford any shelter to ships of the largest class.

Mere tidal harbours are serviceable only to coasters, as their draught of water is usually very inefficient.

It has been very properly observed by the parliamentary commissioners, that deep water harbours can only be formed in the sea by means of breakwaters detached from the main land. Dover Bay affords an excellent site for such a harbour of refuge, there being at a distance of 400 fathoms from the shore a depth of 2 fathoms at low water of spring tides, and but 6 fathoms at 1100 yards, which affords sufficient space for the construction of a capacious deep water harbour, without getting into such a depth for the site of the piers or breakwaters as would add greatly to the expense. A breakwater at a distance of about 1000 yards from the shore, with piers projected from the land towards the eastern and western ends, having four entrances, according to the plan there given, would form a most effectual harbour. It is also suggested that the piers should be built with hard chalk,

and faced with stone; the space inclosed to be about 450 acres, the expense of which is estimated at two millions sterling.

Other sites, as Margate Sound, off Long Nore Spit, at Foreness, and off Beachy Head, have been considered equally eligible for the construction of a harbour of refuge.

River harbours are subject to constant silting up, and to deposits at the mouth, which sluicing very inadequately removes; therefore to form a perfect establishment to receive vessels at all times, it should be at a distance from the main land, with entrances to suit the prevailing currents and winds: to form a hollow island in the ocean, which should enfold within its arms the ships of Britain, and protect them against the elements, often so fatal to many, would, indeed, be worthy of the nation, and rival the great works performed by the Romans.

To see an artificial zone rise from the ocean, covered with buildings containing all that our marine required, and within its circuit ships from all nations riding in safety, would call forth admiration equal to that expressed by Pliny when the port in view of his villa was being formed: a nation's wealth could not be more beneficially employed than in such a work, and though millions might be expended in its formation, in a few years it would be repaid by the securities it offered and afforded. To execute such a project is by no means difficult, as our shores and tidal currents are so thoroughly known.

To attempt to form a harbour on any part of the coast where there is an accumulation of beach, which is moved forwards by the prevailing winds, and lodged in layers along the shore until it rises to nearly high water mark, is useless; no breakwater can be provided sufficient to scour and keep open a passage for vessels in such situations, and a good harbour cannot be obtained.

Under Beachy Head, Dungeness, and several projecting parts of the coast, the beach finds shelter, and forms a bold face, where the water is deep, to the shore, and where, as in the Isle of Portland, a vessel may lie afloat with her bowsprit over the beach, such situations might be rendered fit to hold a large navy.

Walls and Gates of Cities and Towns. — There can be little doubt but that the Romans walled in our chief towns, and taught the Britons a more secure method of defending themselves against a foe who menaced their dwellings than was afforded by earth-works and timber constructions, which Cæsar describes as surrounding their camps and places of resort.

London was encompassed with walls as early as the third century; and in all probability, Helena, the mother of Constantine, added considerably to their strength in the following century. Maitland imagines that the greater portion was rebuilt by Theodosius, who was governor of Britain in 379 A.D.

The direct course of the city walls was as follows: beginning at the Tower, they continued by the Minories, between Poor Jury Lane and the Vineyard, to *Aldgate;* they then curved to the north-west, between Shoemaker Row, Bevis Marks, Camomile Street, and Houndsditch, to *Bishop's Gate*; from thence in a straight line by Fore Street to *Cripple Gate.* They then turned southward to Monkwell and Castle Street, Noble Street, Dolphin Court, to *Alder's Gate*; then south-west, by St. Botolph's, Christ's Hospital, and *Old Newgate:* and southward to *Ludgate;* from thence to Little Bridge Street and the Thames. Stow makes the whole circuit of these walls about 2 miles 1 furlong. Another wall was continued along the banks of the Thames, 1 mile 120 yards in length, to the Tower. These walls were defended at different distances by strong towers and bastions, three of which remained when Maitland wrote his history, in the vicinity of Hounsditch and Aldgate; the height of the walls was about 22 feet, and that of the towers 40 feet. The area comprised within them is computed at 380 acres. A portion of the foundations was measured in 1707 by Dr. Woodward, in Camomile Street, near Bishopsgate, who states them to be about 8 feet below the roadway, and that to the height of 10 feet they were composed of Kentish rag-stone, with single layers of broad tile interposed, at the distance of 2 feet from each other. The tiles were Roman, 17½ inches long, 11½ inches in breadth, and 1¼ in thickness; the mortar was very firm and hard, and the entire thickness of the wall was 9 feet. A portion still remains near Tower Hill.

Numerous tesselated pavements, coins, and other Roman remains, are constantly discovered over the entire area of the ancient city.

York was strongly fortified by the Romans, but the walls which they constructed were probably rebuilt in the reign of Edward I.; in that of Edward III. an order was again issued to strengthen them, and the following is Leland's description of them in the time of Henry VIII. "The towne of Yorke standeth by west and est of Ouse River, running through it, but that part that lyeth by est is twice as gret in building as the other. Thus goeth the waul, from the ripe of Ouse, of the est part of the cite of York. Fyrst a great towre, with a chain of yron to cast over the Ouse, then another towre, and so to Bowdam Gate; from Bowdam Gate or Bar, to Goodram Gate or Bar, ten towres, thence foure toweres to Laythorp a postern-gate; and soe by a space of two flite shotts, the blind and deep water of Fosse, coming out of the Forest of Galtres, defendeth this part of the cite

without waules: then to Waumgate three toweres, and thence to Fishergate stopped up, since the communes burned it yn the time of King Henry VII. Thence to the ripe of Fosse have three towres, and in the three a postern, and thence over Fosse by a bridge,

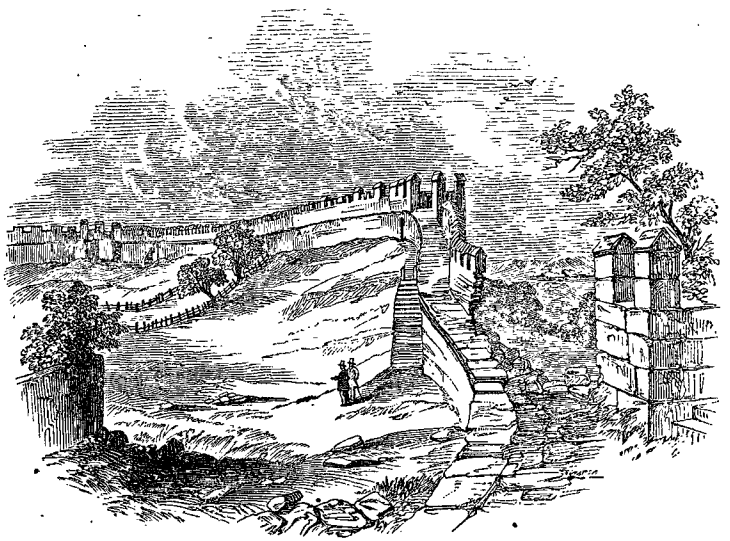


Fig. 401. INSIDE OF THE CITY WALLS, YORK.

to the Castelle. The west part of the cite is thus ynclosed; first a turrit and soe the waule, runneth over the side of the dungeon of the castelle on the west side of Ouse, right against the Castelle on the east ripe. The plotte of this castelle is now called Ould Baile, and the area and ditches of it doe manifestly appeare. Betwixt the beginnyng of the first parte of this west waulle, and Micklegate, be nine towres, and betwixt it and the ripe agayne of Ouse, be eleven towres; and at this eleven towres be a postern-gate, and the towre of it is right agayne the est towre, to draw over the Chain on Ouse betwixt them."

The four gates or bars, by which this city is entered, are admirable examples of those castellated defences of which there are some traces in all our walled towns.

Bootham Bar stands on the north-west side, on the way to Durham, Newcastle, and Edinburgh. On the front are two shields with the city arms, and another much defaced. This bar suffered considerably in the time of Charles I.

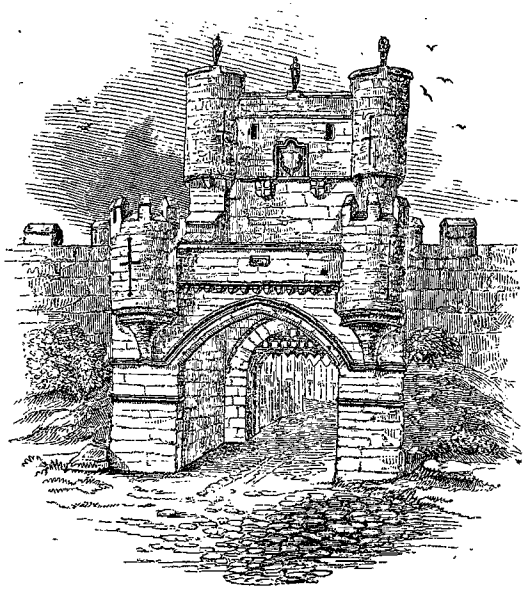


Fig. 402. BOOTHAM BAR.

Monk Bar is the entrance from the Scarborough road; the lower arches are circular, and built of a hard grit-stone, probably at a very early period; the upper portions with the pointed arch, and the picturesque towers at the angles, are of the time of Edward III., and bear the shield of France and England. In this tower are two stories of vaulted chambers.

The plan shows its general arrangement: A, is the bar, B, the barbican, C, the groove of the portcullis, D, the city walls, E, the guard room, F, the stairs, G, the gates, H, the sally port: the clear width between the walls is about 25 feet; the thickness of the walls 6 feet 3 inches, and the total length about 50 feet; the thickness of the two walls equals half the clear opening, and the entire length is double the entire width.

The view of this bar towards the city shows the room over the gateway, which has a stone arch of considerable strength; there is a second room, similarly arched, containing the portcullis and windlass.

Such entrances graced and adorned all our large towns, and Leland describes the walls of Newcastle-on-Tyne as having the pre-eminence. "The strength and magnificence of the wauling of this towne far passeth all the wauls of the cities of England, and of most of the touns of Europe."

General Roy, in the "Military Antiquities of the Romans in Britain," and Mr. King, in his "Munimenta Antiqua," have shown a great variety of examples of the fortifications of the middle ages; and it will be found that the whole were designed and executed after the models

Fig. 403. MONK BAR.

Fig. 404. MONK BAR, INSIDE.

of others, erected during the period of the lower empire of Rome: most cities and towns were defended by castellated walls, a castle, or citadel. In England the Romans constructed a vast number of fortresses; for in every province they conquered, they marked out a camp, and founded military strongholds: to these succeeded the Anglo-Saxon tower and castle, which was made of considerable extent and strength in the time of King Alfred: Arundel Castle exhibits much of the construction of that monarch. When the Danes arrived, some change was introduced in the style; they, it is said, founded Norwich, and threw up those high mounds of earth at Castleton and Coningsburgh. The Saxon princes have left us much of their constructions at Winchester, Exeter, Canterbury, Bamborough, Durham, Porchester, Pevensey, Castleton, Guildford, Corff, Bridgenorth, and Goodrich, and in them we discover that the builders have made use of the tiles and materials which had formed a portion of the Roman fortresses that probably occupied their sites; this is observable at Colchester, Arundel, and Eynesford Castles in particular. When the Normans arrived, they introduced various means of defence by military stratagems, as concealed sally ports, galleries under ground, doorways and staircases which led to nothing, and dungeons only to be approached by trap doors. Even the bishop's palaces were fortified and made strongholds, and the citizens of large towns adopted the same means of defence, as was practised by all the inmates of the larger religious houses throughout Britain.

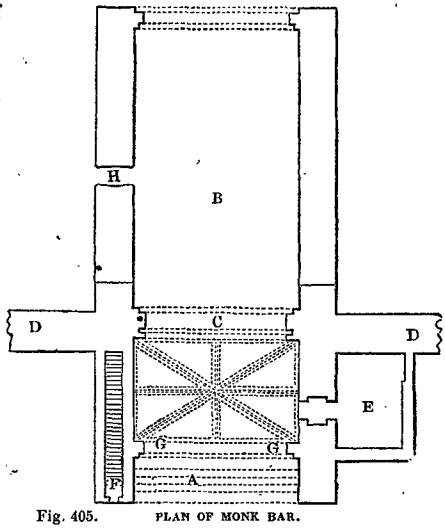


Fig. 405. PLAN OF MONK BAR.

Micklegate Bar. The royal arms displayed are those in use before the time of Henry V. This beautiful gate forms the chief entrance from London; it is built of grey grit-stone, and the towers, which probably are of a later period, are of fine limestone. The portion which is of grit-stone is supposed to be Roman, though Sir H. C. Englefield (*Archæologia*, vol. vi.) has refuted this opinion.

Fig. 406. MICKLEGATE BAR.

The upper parts were probably built in the time of Edward III.; the outwork or barbican, with its angular towers complete, must have added much to the beauty of the entrance.

The portcullises of some gates were of oak covered with iron, and Leland mentions one at Pembroke composed "ex solido ferro."

The Magècolles or machecoulis, under the parapet over the gate, between the salient towers at the angle, contributed greatly to the defence of the entrance: they were introduced into Spain by the Arabs, and subsequently adopted by the Normans and Lombards wherever they established themselves.

The gateways of Caernarvon, Pembroke, Raby, Warwick, Canterbury, and many others, exhibit the perfection of this style, and are models of proportion and construction.

Walmgate Bar is the entrance from Hull; on the front are the arms of Henry V.

The fronts and sides are embattled, and the barbican was similar to the other bar; this

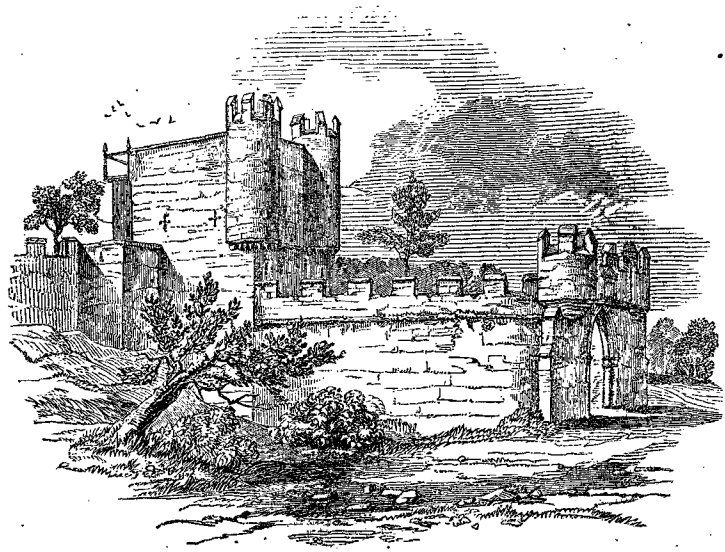


Fig. 407. WALMGATE BAR.

gate suffered greatly in the siege of 1644, and has since been subjected to still greater injury.

The walls adjoining the bar are built upon arches in the foundations, and appear to be of great antiquity.

Chester was a Roman city; its walls were rebuilt by Ethelred and Ethelfleda, about the year 608, and their form is so entirely Roman, that the Saxons made no great changes in the system adopted by their great precursors.

These walls are about 1¾ miles in circumference; the top is paved sufficiently wide for two persons to walk abreast; there are four gates or principal entrances over the north-east bridge and water-gates, besides several posterns. Around the walls were formerly several towers; that called the New, which projected towards the Dee, erected in 1322, was 24 feet in height, and we learn from the archives of the city that the architect was John Helpstone. To the exterior are attached large iron rings for holding the vessels, which, before the harbour was choked up with sands, were admitted up to the walls. Leading to the water tower was another, called Bonewaldesthorne, and the Phœnix tower, from which Charles I. saw his army defeated on Rowton Heath. The Gobelin's tower is nearly destroyed, and the Sadler's tower was taken down in 1780.

Chester is divided by four principal streets, crossing each other at right angles, and the road for carriages is on a level with the basement of the houses, over which are covered galleries or rows, for the accommodation of the foot passengers; these galleries are approached by flights of steps at the intersection and ends of the streets, and the houses extend over them, being supported on stone and timber pillars.

Winchester.—The Saxon walls on the north side of the city are built of flint and hard mortar; at regular distances the ruins of the towers that formerly flanked them may be traced, and in some situations they remain to their full height, being crenated, embattled, and coped with freestone. The form of this ancient city was that of a paral-

lelogram, rounded at the angles, and its gates terminated the principal streets, which crossed at right angles: West Gate, which was the entrance from Rumsey, remains nearly perfect. A ditch, or rather running water, protects the walls on the outside.

At Southampton portions of the walls are said to be Roman, Saxon, and Norman, and it is extremely difficult to discriminate between the works of the several people. The enclosures of a town were usually set out of a sufficient thickness to allow of a walk at the top, which was guarded externally by an embattled parapet. The wall was constructed of the material the country afforded, either stone quarried in the neighbourhood, or flints picked from the surface of the land. Bricks and tiles are occasionally found in the arches to the drains or other openings, and sometimes forming a course through the entire thickness; these walls, like those of the churches and castles of the same epoch, were constructed between cases of timber framework, in a similar manner to the *pisé* walls; and there is sufficient evidence that after the facing was laid on both sides, the filling in or stuffing was made with every variety of material that could be collected, sometimes imbedded in mortar, at others run with liquid grouting, in either case making a hard concrete, capable of enduring for centuries.

Rochester, situated on the Watling Street, was fortified by the Romans, and much of the walls constructed by King Ethelbert remain: they were built in the direction of the four cardinal points, and extend from east to west about half a mile, but from north to south not more than a quarter; they are 4 feet in thickness, and on the east side the height was 30 feet. Edward I., in the year 1290, gave permission to the monks of the convent "to pull down part of the south wall, and to fill up the ditch without the wall, on condition that they built a new stone wall, 5 rod and 5 feet from the former, 16 feet high and well embattled, to stand on their own ground, and to be repaired by them." There were several gates, all of which are destroyed.

It is not possible to enumerate all our city and town walls; they varied in height and thickness according to their locality or importance. Their general character was Roman, and their gates and approaches were defended in the same manner as those of the castles of the wealthier and more powerful barons. What a different spectacle to the traveller must England have then presented! Walled and fortified towns, resembling many on the continent; castles defying admission; religious establishments and colleges within enclosures, resembling fortresses.

The gates of cities and towns throughout Europe during the middle ages bore a strong resemblance to each other. Those at Constantinople, perhaps, served as the prototype of many. The walls of this city extend, on the western side 3 miles, and are fortified by 100 towers. The battlements, machicolations, and entrance gates, are of the same character as those of the castles and walls constructed in England by Edward I. That sovereign, when engaged in the holy wars, as they were falsely termed, had the opportunity of observing the arrangement of the castles in Asia, and the fortifications of the cities, which were surrounded with lofty embattled walls, strengthened by towers of various forms, out of which projected machicolations, galleries, and various other contrivances, both for defence and ornament.

Caernarvon Castle, both a garrison and a palace, has a beautiful entrance, built by Edward I. after his return from the Crusades. It is an hundred feet in height; the gateway has a succession of sharply pointed ribbed arches; there are grooves for three portcullises, above which are circular holes for the discharge of missiles, or for pouring down molten lead.

The Eagle tower has three angular turrets; that appropriated to Queen Eleanor is polygonal, and contains four stories.

There can be no doubt that for the style of our castles we are indebted to the inhabitants of Asia; many towns in India are still surrounded by lofty stone walls, embattled, machicolated, defended by round towers, and with gateways and barbicans in every particular resembling our own.

The Castles of England afford study for the engineer of the most instructive kind; in them all the arts and science of the age are exhibited, and as their plans and forms are adapted to peculiar situations, they do not resemble each other: hitherto they have been regarded solely as contributing to the picturesque character of the country, and as affording subjects to the artist and the historian; they have not been sufficiently studied by the engineer with regard to their construction, nor have they been accurately measured for the purpose of examining their merits as places of defence. A perfect collection of English castles has never been made, which, as they crumble away or are removed to make room for modern changes, will hereafter be regretted. Hertmonceaux, Bodiam, and some others, have been very accurately described, which only tends to awaken feelings of regret that more have not had the same attention bestowed upon them. The square, the circular, the polygonal keeps, which occupy a portion of the area within the outer walls, are generally fine examples of the contrivances of our ancestors; in them were apartments of noble dimensions, well secured and defended from outward attack. Warwick

Ragland, Barnard, Richmond, Pontefract, Ludlow, Goodrich, Caernarvon, Conway Chepstow, Caerphilly, and others, might be enumerated, all of which had accommodation within the circuit of their walls to lodge a considerable body of men.

It is not possible in the present work to do more than select one or two examples, as illustrations of this highly interesting subject; but from measurements, the keep of Coningsburgh and gateway of Saltwood Castle have been selected, as exhibiting in their arrangement and construction the chief and peculiar features belonging to castles of that date.

Coningsburgh Castle, Yorkshire, is a fine example of a fortress at a very early period of our history; and when the sketches of the keep were made, it was, as far as the masonry is concerned, in a perfect condition. It is an evidence that the engineers then understood the setting out of geometrical forms, and the arrangements necessary for the weapons of attack and defence then made use of: Vauban himself could not have contrived a tower capable of greater resistance.

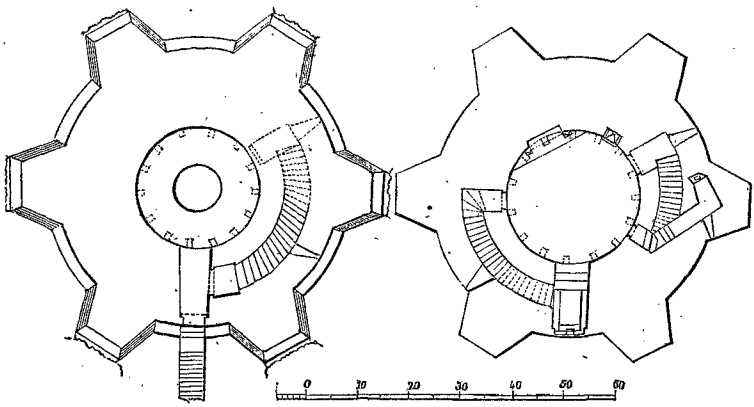


Fig. 408. PLAN. FIRST STORY.

In the time of Edward the Confessor, Arundel Castle is said to have existed, and Domesday Book enumerates forty-nine, after which the Normans laid the foundations of many, and that at Coningsburgh is supposed to have been erected by W. de Warrein about 1070.

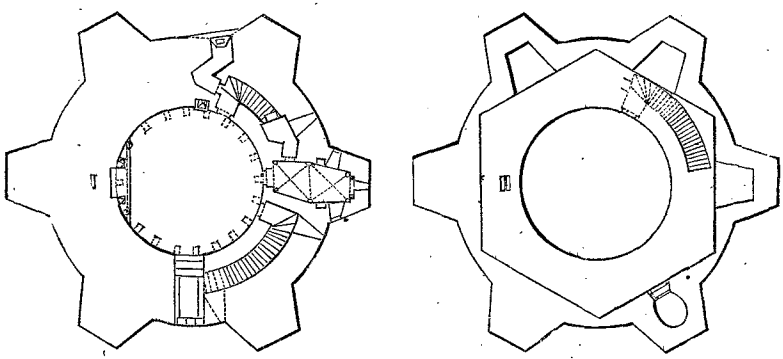


Fig. 409. SECOND STORY. THIRD STORY.

A Norman fortress was a considerable engineering work; a deep ditch was generally cut, the earth taken out and carried within the circuit, to form in some convenient situation a mound, on the summit of which was built a keep or lofty tower, containing several stories appropriated to different purposes.

In the wall on the inner edge of the ditch was an entrance gateway, before which was

a barbican or watch tower, communicating by means of hidden passages with the strong tower on the mound.

The Normans constructed a castle in every lordship, and when material was not easily obtained, they frequently imported stone from Caen for casing the walls, and for the ornamental portions of the interior, the internal and external facing being filled in with a concrete composed of pebbles, flint, or chalk, run with fluid mortar. The great thickness given to the walls enabled their engineers to practise within them staircases, guard-rooms, chapels, and every kind of accessory apartment that the inhabitants could require during a siege. The keeps of London and Dover, Hedingham, Norwich, Porchester, Scarborough, Colchester, and others, though dismantled, convey to us an idea of the great discernment and skill of those under whose direction they were raised.

At the entrance story of Coningsburgh, the internal diameter is 22 feet 1 inch, the thickness of the walls where the buttresses are attached the same. Between the buttresses it is only 13 feet 7 inches. The entire diameter, measured through to the flat outer face of the buttresses, is three times that of the interior. The six buttresses are half hexagons, and on this floor solid throughout; each of their sides internally measure 8 feet 10 inches, the distance apart is 12 feet 4 inches, and from angle to angle in a straight line 26 feet.

The entrance, 24 feet from the ground, is approached by a lofty flight of steps, and is only 4 feet 4 inches in width; after passing through half the length of this passage, on the right, in the middle of the wall, is a stone staircase conducting to the apartment above, to which the only light admitted is from the aperture shown between the buttresses.

In the centre of the floor of this apartment is a circular hole communicating with a lower apartment, at the bottom of which was probably the well that supplied the tenants of the keep with water during a siege.

Some writers suppose that this keep was constructed by the Saxons, and that William the Conqueror bestowed it upon the husband of his sister Gundred, but of this we have no direct evidence: the castles of the Saxons were often entered as this was, by an aperture at a considerable height from the ground, either by ropes or a wooden ladder. The reader is referred to the "Archæologia" for a description of a castle at Eynsford in Kent, by the author. The only entrance is at the top of the wall, and no one could have gained admittance without being hauled up, or supplied with a wooden ladder.

The first story has a fireplace of a curious construction, perhaps the earliest example we can produce of such a contrivance in England. Light is admitted over the entrance doorway by a double opening; and in one of the buttresses is a closet, entered through a passage 2 feet 6 inches in width.

A staircase in the thickness of the wall conducts to the floor above. The mantel of the fireplace is formed of nine stones, so cut as to hang on each other, and preserve a level line below, showing all the properties of a flat arch. Above this arch runs a level moulding, on which the masonry rests, bevelled over so as to gather the flue into the thickness of the wall; the chimney at Coningsburgh seems to have been built up at the same time as this portion of the keep; the opening is 7 feet 3 inches, and depth 18 inches; on each side is a triple column, with capitals and bases.

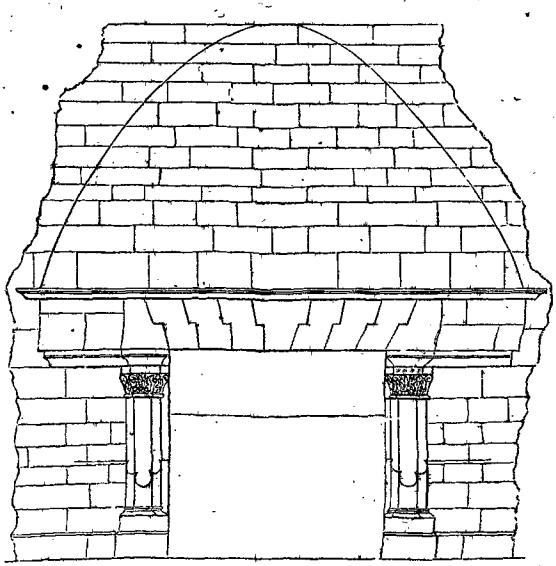


Fig. 410. CHIMNEY OF CONINGSBURGH CASTLE.

The thickness of the walls at this story is 13 feet 6 inches, and around the interior face the stone corbels that carried the timber floor still remain.

The second story, 27 feet in diameter, appears to have been entirely devoted to the baron and his family;

there is a fireplace, closet, chapel, and other conveniences, hollowed out of the buttresses and walls.

The chapel, with an inner room adjoining, remains in a very perfect state, and the architecture which decorates it is in the pure Norman style; the zig-zag is peculiar, and the ornaments comprised in the plain faces have a truly Greek character. The light is admitted by quatrefoil openings, of a very early date; the whole is vaulted, with the ribs resting on very enriched capitals attached to the walls. There are several niches worked out of the walls in various places; some contain stone sinks or troughs, and a water-closet at the end of a winding passage in this floor is contrived with admirable skill.

The clear width of the fireplace on this floor is only 5 feet 4 inches, and height about the same; the weight of the breast of the chimney is discharged by a flat arch of eight stones, constructed like that below. The corbels around the walls remain, on which the timbers rested which carried the oak floor.

The light in this apartment is nearly sufficient for any modern building. The conveniences attached, and easy access to the rooms above and below, give an excellent idea of what the barons considered essential to their wants; and a family at the present day would have no difficulty in finding accommodation in a structure so arranged.

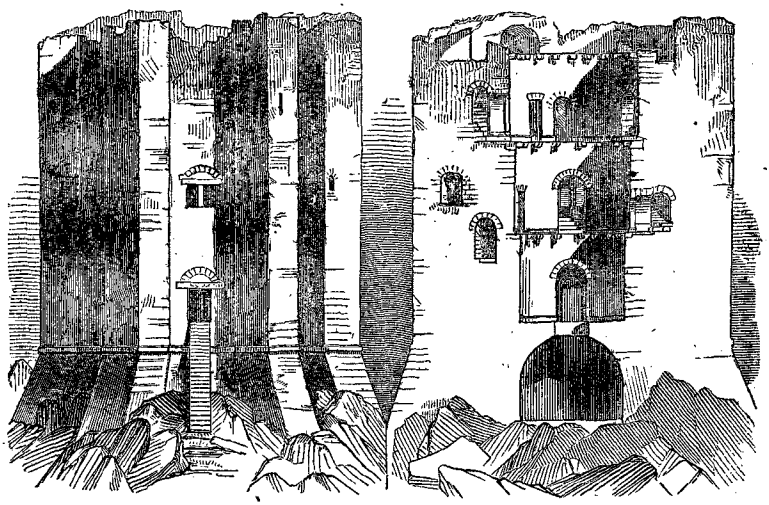


Fig. 411. CONINGSBURGH CASTLE, YORKSHIRE.

The upper floor has within one of the buttresses an oven, sufficiently large to have cooked all the provisions for the entire garrison; the other five buttresses have recesses within them, for the protection of the guard, who were constantly on the watch to announce the approach of an enemy, and prepare for defence against an attack. The battlements and machicolations around, which must have greatly added to the effect of the upper portion, have long disappeared.

The thickness of the main wall is here 12 feet 4 inches, and the outer face is perpendicular from the level of the ground floor, the diminution in thickness being always caused by giving an addition to the internal diameter.

The village of Coningsburgh, situated a short distance from this beautiful remain, is 5½ miles from Doncaster, on the road to Sheffield; it was no doubt a British station, as the site was called Caer Conan, or the Royal Town. By the Saxons it was known as Cyning or Conan Byrgh, and it very probably formed the stronghold of Hengist when he was defeated in 487 by Ambrosius. The tumulus near the entrance has been supposed to cover the body of the Saxon chieftain.

Saltwood Castle, Kent. This entrance gateway is in a very perfect state, and shows the style of architecture adopted for such edifices in the 14th century. Archbishop Courtenay resided here, and under his directions the castle received many additions and embellishments; his arms are quartered on the shields over the gateway, whence we may infer that it was built during the time he possessed it.

The gateways of cities, religious houses, and castles, during this epoch, combined architectural beauty with defence. The lofty towers, which flanked the entrance, were carried up high above the battlements of the curtain walls that shut in the court-yards;

these were crowned with a parapet, resting on corbels, and in the centre division between the towers were deep and projecting machicolations, from which might be hurled a variety of missiles upon the heads of those who had crossed the drawbridge, or were endeavouring to force the portcullis or fire the gates.

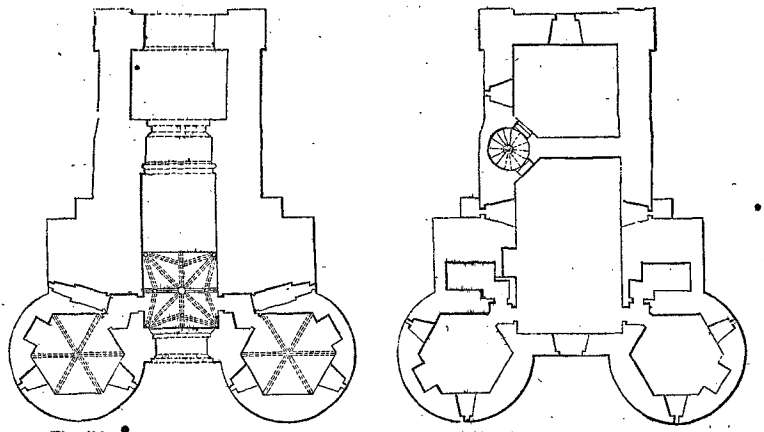


Fig. 412. GROUND PLAN OF SALTWOOD CASTLE, AND FIRST STORY PLAN.

Catapultæ, mangonels, balistæ, springals, tribuli, arcubalistæ, multones, barfreni, skaffauts, and various other instruments and machines were here lodged, ready either for defence or attack.

On comparing these defences with those attached to the entrances of Roman or Greek cities, we find that the orders of architecture are omitted, but many oriental contrivances are substituted, which give a peculiar effect and character; there is the same solidity of construction and quality of material in both, as well as great similarity of workmanship. All the vaults and arches, winding stairs and passages, are formed in the same manner; concrete is universally employed, to fill in between the outer faces of the walls in the castles of the middle ages as in those of the Roman fortress. The construction is Roman, and the military features are mostly of eastern origin.

The lower or entrance floor of Saltwood Gateway has considerable strength; it is flanked by two circular towers, which contain hexagonal apartments.

From out to out this gateway measures 56 feet 6 inches, and the space between the towers is 12 feet 2 inches. The entire depth, from the face of the wall between the towers to that at the rear, is 56 feet 6 inches.

The floor above contained many convenient apartments, admirably proportioned, and so arranged as to be used for defence when occasion required. Each of the towers had a chamber, 13 feet 2 inches in diameter, lighted by two narrow windows, between which was a fireplace, the flue being continued to the summit of the tower.

A spacious room, 29 feet by 17 feet, and another 16 feet by 15 feet, occupied the space over the gateway; the walls are 5 feet in thickness, except where the towers unite with the straight portions, and there is a square mass of masonry and rubble, solid throughout, except where hollowed out for the purposes of obtaining a guard room, 8 feet by 4 feet.

Bridges.—We have no evidence of any bridges of consequence being erected previous to the Norman conquest, and the names of our principal towns on the banks of rivers, having the word ford attached to them, seems to confirm the opinion that none existed. Following the course of the Watling Street, or great Roman road over the Medway, we meet with Aylesford; over the Darent, Dartford; the Cray, Crayford; the Ravensbourne, Deepford; and so with most other rivers in England. The capital in all probability would first have a bridge in preference to a ferry, which is noticed over the Thames. We have an account of a timber bridge constructed by Etheldred in 1002, which lasted many years, and also of another built in 1165.

The first stone bridge was begun in 1176, by the celebrated Peter of Colechurch, who continued the work during the reigns of Henry II., Richard I., until the second year of the reign of King John, when he died, and was buried in the crypt of the chapel erected over the centre pier.

It appears to have been the custom with the society called the Brothers of the Bridge, when any member died during the superintendence of any important work, to have his

remains entombed within the structure; and as all great bridges were provided with a chapel and crypt, every means was afforded for the performance of the annual rites that were usually instituted. The great bridge at Avignon, when built by S. Benezet, or Johannes Benedictus, the first brother and founder of the order, had such a chapel, where he was buried in 1222.

At the death of Peter of Colechurch, the work was not delayed; another brother, of the name of Isembert, master of the fraternity at Xaintes, and who had recently completed bridges at that place and Rochelle, was appointed to carry it on; in a few years the bridge and its chapel were entirely completed; the latter he endowed with two priests and four clerks, constantly to perform service therein. The chapel was dedicated to St. Thomas of Canterbury, and contained a table, on which were inscribed the names of all the lands and gifts given for its support.

This stone bridge was 926 feet in length, 15 feet in width, and 60 feet in height above the level of the water. It contained a drawbridge, and nineteen broad pointed arches, with massive piers, varying in solidity from 25 to 34 feet, raised upon strong elm piles, covered with thick planks, bolted together.

The breadth of the first arch on the city side was 10 feet, the second 15, the third 25, the fourth 21, the fifth 27, the sixth 29 feet 6 inches, the seventh the same, the eighth 26 feet, the ninth 32 feet 9 inches, the tenth 25 feet 6 inches, the eleventh 16 feet, the twelfth 24 feet 6 inches, the thirteenth 25 feet 8 inches, and the breadth of the drawbridge, or fourteenth arch, 29 feet 4 inches. The breadth of the chapel which stood on the centre pier was 20 feet, and its length 60. Mr. George Vertue engraved this bridge and its stately chapel and crypt, and published them in 1748; after his death his widow presented the plates to the Society of Antiquaries.

The water-way between the piers was not more than 336 feet 9 inches, and if we make some allowance for the footings or increased size of some of the starlings, we shall find that nearly two-thirds of the stream was occupied by piers, and only one-third allowed for water-way.

When the bridge was demolished, the tomb of Peter of Colechurch was found embedded in the tenth pier from the city side; it was 7 feet in length, 30 inches wide, and 24 in height; it was also discovered that the piers were formed upon piles driven into the bed of the river, cut off at low water-mark, with a filling in between the heads of stone and chalk: on the top of the piles blocks of Kentish rag were bedded in pitch.

The Traitor's Gate, at the north end, was built about 1426; in 1437 the great stone gate, on the Southwark side, fell into the river, and according to Stowe destroyed two of the arches adjoining.

Monnou Bridge, over the river of that name, where it joins the Wye at Monmouth, as it existed some years ago, was a fine example of a fortified bridge; the arches were constructed much in the same manner as the severy or division of a cathedral church; ribs were framed

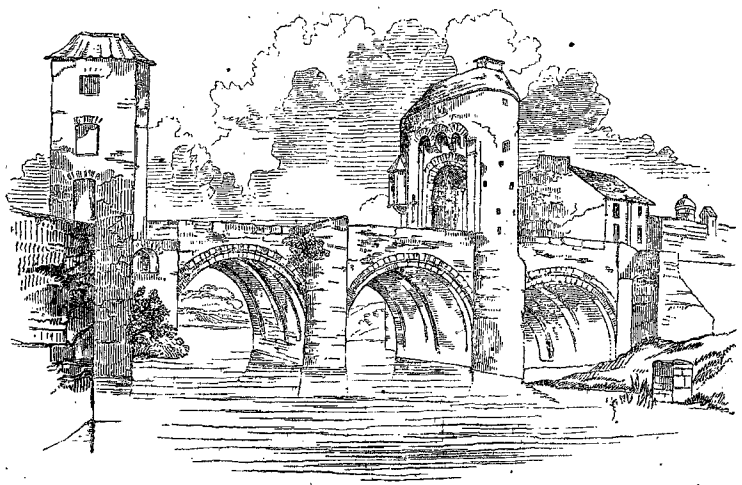


Fig. 413. MONNOU BRIDGE.

from one abutment to the other; after they were gathered over, and united at the top of the vault, the spaces between were filled in with masonry; the whole bore some resem-

blance to a work in carpentry, and though executed in stone could only be deemed the centre or contrivance on which was laid a bed of beton or concrete, which hardened into a mass, and formed the solid construction of the bridge. The mason and carpenter during the middle ages employed the same principles; wood and stone were often treated in a similar manner, and the same mouldings and forms were given to both, without reference to their different qualities.

Bishop Auckland Bridge over the Wear, erected in 1388, has two segmental arches, the largest of which spans 100 feet 5 inches, and has a rise of 22 feet; the other has 91 feet 5 inches span, and rises 20 feet. Each of these arches is built of three rows of voussoirs, 22 inches in depth: this example is, perhaps, the earliest in England where the segment was introduced. The three rows of voussoirs performed the office of as many ribs, and by this arrangement a simple centre might be made to serve for the execution of the whole.

There are several small bridges remaining, in which the Gothic ribs are admirably preserved; that which crosses the moat at the palace at Eltham is a fine example: another over the Darenth at Eynesford in Kent, though small, is a good specimen.

Rochester Bridge, Kent. In a line with the principal streets of Rochester and Strood formerly stood a wooden bridge, which is mentioned as existing at the commencement of the 13th century. Lambard, the historian of this county, has given several regulations for its repair, copied from manuscripts in the library of Rochester Cathedral, which were collected by Bishop Ernulphus, who was elected to that see in the year 1115.

From these ancient writings we learn that the bridge consisted of nine stone piers, placed at equal distances, and the width of the river was 26½ rods, or 440 feet, nearly the same breadth as it is at present.

These ten divisions were each 43 feet from the centre of one pier to the centre of the other, so that the cills or beams were 43 feet long; and each bay had three of these timbers to make out the width of the bridge. Across these beams were thick plankings, probably about 10 feet in extent. It would appear that the sides were not protected, as in the Registrum Roff. mention is made of a rash young man, son of Earl Aufrid, who, in the reign of Edward I., not alighting from his horse, as was customary, when passing the bridge, the beast took fright, leaped into the river, and both were drowned. A wooden tower, constructed with marvellous skill at the east end of the bridge, was used as a gate as well as a defence.

This bridge was probably erected at the cost of the proprietors of the manor, who afterwards kept it in repair. The manors are all mentioned, and two of the holders were annually elected as wardens and overseers of the bridge.

This wooden structure was burnt in 1264, by Simon Montfort, Earl of Leicester, but the timber work was soon after restored, for in the year 1281 we find, that after a severe frost, the ice struck with such impetuosity against the stone piers, that some of them were swept away, and the others much damaged; in this state it was left until the reign of Edward III., when it was again put into repair.

Sir Robert Knolles, after his return from France, where he had attended Edward III., in all his successful campaigns, founded a stone bridge at his own cost, probably about the year 1387, for it was completed in the fifteenth year of Richard II., as appears by a statute made "for repairing and supporting the new stone bridge of Rochester," which is stated to contain more in length than the old bridge. The sum of the various portions allotted to the places and manors for the repairs in future amounts to 566 feet, 1⅛ inch. This bridge was considered one of the finest at that time in England; the breadth was 14 feet; it had stone parapets and eleven arches, resting on substantial piers, well secured on each side with starlings. At the east end, and fronting the passage over the bridge, is a chapel which was erected by Sir John de Cobham.

It appears that after this bridge was completed over the river, at about 40 yards higher up the stream than the old bridge, it was enacted by two statutes, one made in the fifteenth, and the other in the twenty-first year of Richard II., that it should be repaired by the manors and places there specified. The statutes also enact that the persons, manors, places, and bounds, should be considered as a community, and that they should choose two men annually, who should be called wardens, and have the superintendency of, and provide for the repairs of the said bridge. It also allowed them to purchase lands to the amount of 200*l.* per annum, and to hold them as wardens of the said bridge; they were to be accountable to auditors to examine the receipts, disbursements, &c.; and in the ninth year of Henry V. a statute was made confirming the two former acts, and allowing the wardens to have a common seal, and to plead in any court by the name of the Wardens of the New Bridge at Rochester.

Sixty years after it was finished, it required some repair, which was partly done by the prior and convent of Rochester, assisted by Henry VI.; and in the year 1489, John Morton, Archbishop of Canterbury, published a remission from purgatory for forty days of all manner of fines, to such persons who would give any thing towards the repairs, as at that time the bridge was very much broken.

Lambard says that in the time of Elizabeth, the revenues were converted to private uses, and that the county was charged with a toll, and fifteenth, to supply the public wants; yet the bridge went out of repair, and was threatened with absolute destruction.

Sir William Cecil obtained from Queen Elizabeth permission for certain knights and gentlemen of the county to examine and report upon the defects, and a statute was passed in the eighteenth year of that queen's reign, for the perpetual maintenance of Rochester Bridge. Another statute, passed nine years after, makes some further provisions, the former funds proving inadequate. About the middle of the eighteenth century three of the arches were rebuilt, and the approaches greatly improved, out of the funds derived from the estates belonging to the bridge.

Timber bridges of very simple construction were long made use of over the wide rivers in England, but no skill was exhibited in the framing, nor any further mechanical principle than that of strength; trees merely squared, were laid side by side, at right angles with the stream, supported on a single row of perpindicular piles, or several rows parallel to each other, capped and cross braced, and sometimes planked over to the height that the water rose, the space between being filled in with stones. The roadway was cross-planked, covered with chalk and gravel, and frequently required repair, in consequence of the air not being admitted to the upper side of the planking.

Battersea Bridge over the Thames, nearly 900 feet in length, still remains an example of such rude and primitive style of construction, and several others might be named.

Croyland Triangular Bridge is alluded to in a charter of the year 943, under the title of "The Triangular Bridge of Croyland," and though the present structure does not warrant so early a date being assigned to it, the construction is nevertheless curious; its style belongs to that in use at the commencement of the 14th century.

This bridge is situated on the west side of the abbey, at the confluence of three streams, the Welland, the Nyne, and the Catwater or Catch-water Drain, all which unite and pass under it, and proceed thence by Spalding to the German Ocean. Three pointed arches, having their bases or abutments placed on the points of an equilateral triangle, meet in the middle, and thus form three distinct watercourses, as well as three roadways; the singularity of its arrangement has always made it an object of the greatest curiosity, and it is, perhaps, unique as a specimen of bridge building, though its utility is somewhat destroyed by the steepness of the ascent, which is almost too great for horses.

Each arch has three stone ribs, and the whole nine meet together in the centre; the bridge is of stone, and had it not been raised on such lofty abutments, long ere this the torrents which flow occasionally under it must have swept it away; the roadways are paved with pebbles, and have more the character of steps, so that carriages generally pass under, and not over it; the construction is thus rather calculated to excite wonder for its peculiarities, than admiration for its utility. When Croyland was established, and the arts began to revive in Europe, we find the same skill evinced in the construction of bridges, so necessary for the security and convenience of the neighbourhood, as in the religious edifices themselves, and this might have arisen from the example set by the fraternity before alluded to, the Order of the Brothers of the Bridge. Croyland Abbey, which is near the bridge, was situated in a morass, and the foundations of its stone church were laid, according to Ingulphus, who was abbot at the commencement of the eleventh century, on innumerable large timber piles, driven into the ground, the softer parts being covered with earth brought in boats from a distance of several miles.

Bridge over the Ouse at York, taken down some years ago, was remarkable for the span of its pointed arch; it was constructed in the reign of Elizabeth. The chapel and abutments were probably built before the commencement of the thirteenth century.

Laythorpe Postern and Bridge belong to the same period; the tower had gates defended by a portcullis.

Many of the chapels constructed in bridges during the thirteenth century, like this example, were rich in architectural embellishment, and endowed with estates of considerable extent for the maintenance of the bridge, and for the support of the priests appointed to perform the service within them. The chapel sometimes occupied the middle pier, and each extremity of the bridge was protected by a machicolated and strongly embattled gateway. The chapels were usually dedicated to St. Nicholas, he being the patron saint of sailors, and the Brothers of the Bridge scarcely ever terminated their work without creating some memorial to this favourite saint, or votive offering to that Holy Spirit which presided over them and their designs.

The bridges being very narrow, it was necessary, as the use of wheeled carriages became more general, to destroy these highly ornamented and picturesque structures, to obtain a convenient access to the cities and towns with which they communicated. The passengers seated on the roof of the mail and ordinary coaches could not pass without danger under the arches of the gateways, and where it was not practicable to turn the thoroughfare, they were necessarily demolished.

It would be an endless task to enumerate all the bridges erected in England by the free-

masons of the middle ages; many were built, as has been observed, in the same manner as the vaults of the chapter houses and cathedral churches; after the piers were carried above

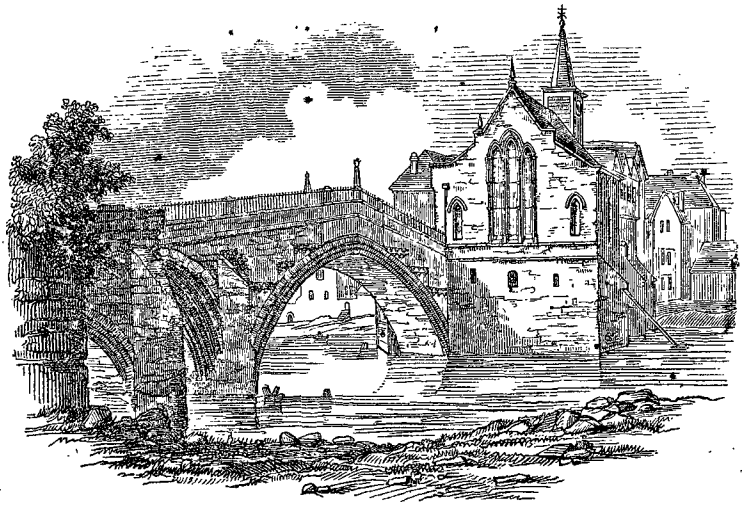


Fig. 414. OUSE BRIDGE, AND ST. WILLIAM'S CHAPEL, YORK.

the level of the stream, ribs of stone spanned the opening from one pier to the other, and supported a rubble construction laid above them, an arrangement combining both economy

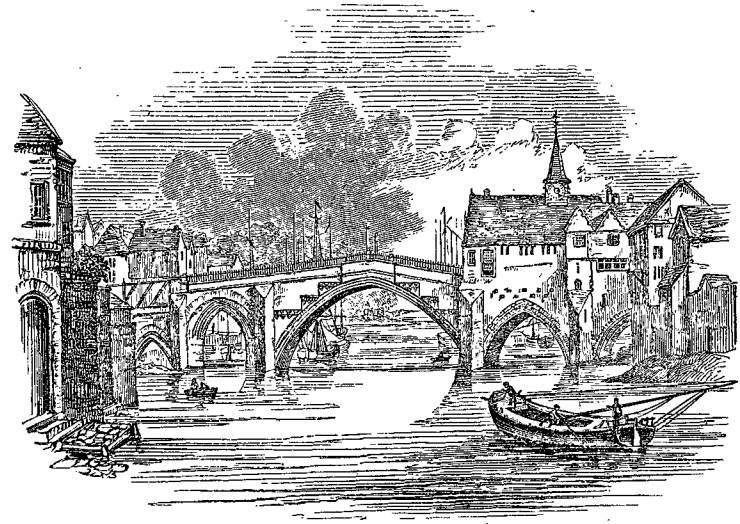


Fig. 415 OUSE BRIDGE, AND ST. WILLIAM'S CHAPEL, YORK.

and convenience. In subsequent instances we see one or more rings of voussoirs spanning a river, upon which slabs of stone are laid, and the bridge completed; but it must be borne in mind that such ribs simply serve the purpose of centres, and cannot have the strength of our modern bridges, where a wedge-like form is given to every portion of the stone.

Between the towers of Lincoln cathedral, and above the vaulting, is a stone girder, composed of numerous voussoirs, arranged within the segment of an arch, whose radius is 91 feet; the abutments are extremely solid, and the girder, which exhibits a horizontal surface above and concave below, is about 20 inches deep at its abutments, and 11 inches in

the centre; the shallow depth given at the key proves that there strength is not required, so long as the extremities are well maintained in their position. The arrangement of the stones, as in this curious girder, is a strong proof that at its introduction the theory of the arch was understood, and, its use not being apparent, we are tempted to imagine that it was so placed as a model for study, and an evidence of its practical strength.

After the reign of Henry VIII. bridge-building underwent a considerable change; timber constructions again became very common, and some of the principal rivers were crossed by them. In the year 1636, Inigo Jones erected a bridge at Llanwast in Denbighshire, after the method practised in Italy, which was the model for some of the succeeding structures.

It was formed of three segmental arches, the middle spanning 58 feet, with a versed sine of 17, and the breadth of the soffite of the arch 14 feet. The depth of the voussoirs, measured on the face, was 18 inches, the piers were 10 feet in thickness. The pointed arch was no longer used, and the defences of towers and gateways were unnecessary; the passage was made more convenient, and the roadway approached a horizontal line, in consequence of the substitution of vehicles for the pack-horse for the transit of merchandize.

At the commencement of the eighteenth century we find evidences of an attempt to improve the bridges throughout England, but there is no account of any principles by which the engineer could be directed, nor are there any names upon record to whom such constructions were particularly entrusted; what had been done in Italy does not seem to have found many imitators here, and though Newton had discovered the principles upon which mechanical science was based, it was long before the equilibrium of the arch occupied the consideration of practical men. Dr. Hooke had, however, drawn attention to the figure which a heavy chain or rope assumes when suspended at the two ends, and shown the properties of the *catenaria*; but it was not then applied to the construction of bridges.

One of the first essays on the subject was written by Isaac Gadsdon, and published in 1739; he sets forth very clearly the nature and properties of arches, mechanically considered, with respect to their shape and duration; and, as this essay is interspersed with some remarks on the intended bridge at Westminster, some portion of its contents may be interesting as evidences of the state of knowledge on this subject at the period he wrote.

"By the word arch is to be understood some regular curve or crooked line, which, when applied to practice in building, is always put with the convex side uppermost, in order to support some weight. But without the abutments it would not support itself, for the action of gravity pressing upon it would soon tumble it down; and if a flexible or malleable body, would soon reduce it to a straight line. From hence it is plain that the strength of all arches depends upon the abutments, and that dependency is in proportion to the height they rise from the chord line of their respective arches.

"The truth of this will plainly appear by setting up two pieces of wood in the shape of levers, one against the other, in the nature of a pediment. The pediment requires a greater weight or resisting power, to be placed at the foot *e, e*, to keep it from falling in the arch A, than in the other; therefore the arch B will support a greater weight than the arch A, if their abutments are equal. The reason of this is, that the lines *a, a*, are nearer a perpendicular than the lines *o, o*, for if those before-mentioned pieces of wood were placed perpendicular one against the other, with a hinge at the top, and wheels put in the bottom, for the sake of experiment, to take off the friction, they would in that position want no abutment to keep them together at bottom; but if they are a small space asunder at the bottom, they will want an abutment to keep them in that position, otherwise they will run one from the other, and the further they recede from each other, the greater must be the resisting power or abutment be to keep them from falling. From what has been said, it appears that gravity acts on these two levers, according as they are elevated or depressed, and if so, it must be in some proportion, which proportion may very nearly be determined by the following figure G, where the theory depends upon that of the steelyard, which, for the better understanding of what is to follow, I shall endeavour to explain by the figure E.

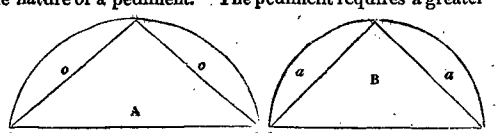


Fig. 416. Fig. 417.

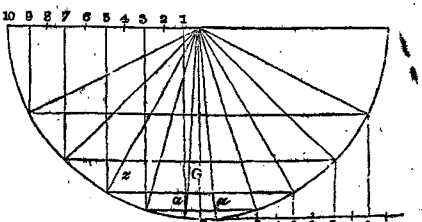


Fig. 418.

"Let the line *c* and *o* represent the beam, and O the centre of a pair of steelyards, and suppose two weights, as *n* and *r*, were to be hung at equal distances from the centre

O, and the other part of the beam cut off, they would then hang in equilibrio, that is, n and r would be equal. But if the other part of the beam was to be added, and the weight n was carried on the beam as far as the number 10, and suppose the weight was but one pound each, then I say that the weight r must have 9 pounds added to it to make it balance the weight n, when removed so far from the centre. But here it is necessary to observe, that in making these instruments, the weight that is occasioned by the length of the beam is always accounted for before they begin to divide, and it is very easy to discover what weight did belong to a pair of steelyards, supposing it to be lost, by taking the distance between the centres of the hooks, that is, between O and r, and apply it to the proper edge, and the division there will tell you what the weight should be,

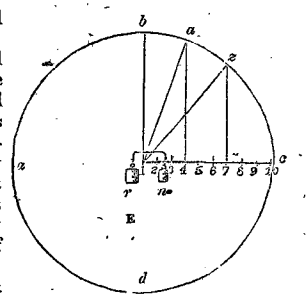


Fig. 419.

for it is that distance multiplied into the whole length, as you may see in the figure. But here in this present case the beam is only imaginary, for it is the distance from the centre that occasions all those different gravitations, for if we suppose the circle a, b, c, d, to be a wheel, and o its centre, and a weight of one pound to be fixed at its periphery at b, and the wheel to be turned round, the weight when it is got to a will be 3 pounds, and at z 5 pounds, and the gravitation of such a weight will increase in the same proportion as if it was carried along the beam e, as you may see by the divisions. By this useful instrument may also be discovered the power of the lever, from a perpendicular to a horizontal position, and may very justly be called a scale, to measure all mechanical powers that act from centres, and notwithstanding our present subject be two levers set up one against another, yet I believe the next figure will make it appear very plain that they also depend on the same theory, and are subject to the same laws of gravitation. For as the two levers a, a, in the figure G, support one another at the top, and prevent their falling or acting like levers, yet I conceive that gravity will act on the bottoms, when the friction is taken off by wheels, in the same proportion as if they were turned end to end, according to the left hand side of the figure G when turned upside down, that is, to put the confined end downwards, and let the upper ends fall one from the other: I say, in the fall of such a lever, the gravitation would be increased in the same proportion as is there set down, for if the lever a, by falling from the perpendicular line G, should have gained a force of 1 pound, it would at e have gained 3 pounds, at z 5 pounds, and so on in proportion, as was gained by the weight at the periphery of the wheel in figure E, until it becomes horizontal. In the same proportion I conceive gravity to act at the bottom of the two levers, a, a, that is, if at a they should want an abutment of 1 pound at each foot to keep them in their position, at e they would want 3, and at z 5, and so on in the same proportion, as they are set down in the right hand side of the figure G, until they become so far extended, as to lie level on the plane they moved on: from what has been demonstrated from figure G, it is plain that gravity acts on pediments, according as their sides are elevated or depressed; and if so, it must certainly act on all arches in the same proportion, as their inscribed pediments are to one another in respect to their height. And from hence may be discovered how much weight one arch will bear more than another that is the same width, and hath the same abutments to support it; that is, if the lower arch D will bear 500 pounds weight, the arch a will bear 600, and the arch b 700, and so on according to what height you rise may the weight be increased, which will always be in proportion, as the sides of the inscribed pediments are to one another, when their chord lines or widths are the same. Notwithstanding I have given this method to show how much one arch will bear more than another of the same width and abutment, yet I do not pretend to know

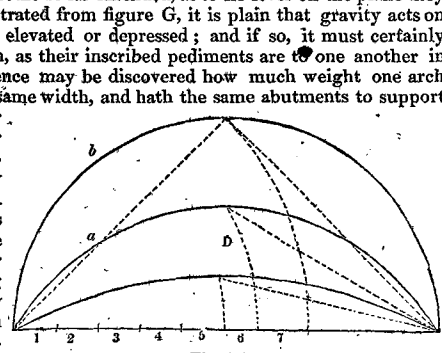


Fig. 420.

how much weight any arch will bear, for there is no arch that I know of that can be said to bear all the weight that is built perpendicularly over it, because that part hath communication with the rest of the building, and cemented to it in such a manner, that takes off a considerable part of the weight that would otherwise press upon it if that communication was destroyed; and I may venture to say, that it is from this reason that arches sometimes become so loose, that their keystones are almost ready to drop for want of sufficient weight to keep their parts together. From this observation it is plain that all arches want

a weight proportionable to the height they rise, to keep their parts firm in the situation they are first placed, for it is very reasonable to think, that the arches of London Bridge would not have remained so entire to this day, if it was not for the weight of houses that are erected thereon, which must certainly prevent those frequent shocks and shakings that it must otherwise have suffered, by loaded carts and cars, and other vehicles of burden, that daily pass and repass thereon.

"But to proceed to make some observations on the shape of arches in respect to their duration. I think the most common sort that are to be found amongst our modern buildings are either semicircles, segments, or semi-ellipses, which I must own have an agreeable effect on the eye, because they are part of regular figures, and make a good appearance in a building if they are well proportioned and well introduced; but this is not always observed by our modern builders, for I have often seen a passage of 3 feet wide with a semicircular arch, and a gateway of 10 with an elliptical one, whose height from the springing hath not exceeded 20 inches; such a one cannot be supposed to be of any long duration without very strong abutments, unless the weight be discharged by a concealed breastsummer, or very little laid thereon: in such cases ornament is consulted more than strength, for the arch of 3 feet being a semicircle will bear above ten times more weight than the elliptical one of 10 feet with the same abutments, by reason of its flatness and double centres, which must render it very weak and unfit to support a great burthen, I mean such an ellipsis whose transverse diameter is placed horizontal; but if you take an ellipsis the other way for an arch, and let the conjugate diameter be horizontal, then it will become altogether as strong, and may very justly be esteemed the best sort to support a great burthen, excepting those formed by the *catenarian*, which I shall endeavour to prove the strongest of all, and the most durable. But for the truth of what I have asserted in respect to the elliptical arches, I must refer to a very easy and familiar experiment, which is, to take an egg, and try whether it will not bear a great deal more weight on the ends than it will on the sides before it burst; such an experiment seems to me to put this matter out of the reach of contradiction, and will justify the theory I have hitherto endeavoured to explain, namely, that all arches will bear a weight proportionable to the height they rise from their springing, if their chord lines or openings are the same, let the shape be what it will, although it must be allowed that some sort of shape will bear more weight than another of the same height and abutments; for if the elliptical arch was a segment of a circle of the same height, it would add much to its strength, by reason that a curve would be more uniform, and approach nearer to a *catenarian* than it was before, in the flat elliptical form, for it is my opinion that the strength of all arches would be increased the nearer they approach that firm arch of nature, for so I must call it, by reason it is formed by action of gravity, which must be allowed to be a natural cause.

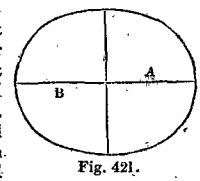


Fig. 421.

"This curve or arch may be discovered by suspending a chain, or flexible line, that is not very light, from two horizontal points or nails; the curve or arch that such a line or chain will form is called the catenarian. This line, as I before observed, is formed by the action of gravity, which acts on all bodies according to their density or quantity of matter they contain, if their form and shape are the same; therefore, if gravity by its action on a slack line or chain form the arch *a*, it is very plain that if it were turned upside down it would form the arch K, which, consequently, must resist that action in the same proportion as the other gave way, that is, K would become an arch of equal strength in all its parts, and for that reason must be certainly the best shape for any arch that is to bear a great burthen.

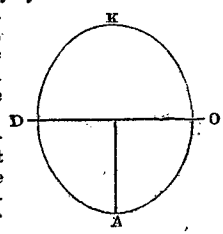


Fig. 422.

"But as the properties of the catenarian arches are so far concealed that it would be very difficult to assign any centres that would strike the same, for if they are very flat they appear like segments of large circles, but if you endeavour to form a semicircle by letting the line drop half its opening, it will then appear elliptical, and as you drop it lower, it seems to approach the hyperbola, so that the distant appearances it makes in these different stations must render it very difficult to find out proper centres to strike them out. But those that have occasion to apply them to practice, may observe the following method, which may answer the purpose very well if it be carefully observed, that it is to take such a line as before mentioned, and rub it with chalk or charcoal until it be fit to leave an impression; then, on some flat plane or board that is large enough for the use, fix in two nails horizontally, according to the width or span of your arch, and from thence let the line fall as far below the horizontal line as you would have the arch to rise above it; then carefully press the line hard enough to leave the impression, and that will be the arch required; then

move the nails from *o* to K, according to the margin you intend to show in the front, and from them let fall the arch *m*, and that will limit the border or margin, which may be divided, and a mould made to fit the curve in the same manner as if the arch was in any other form, as you may see in the figure, which in practice must be turned upside down; but, as I observed before, that the lower the line was let fall, the nearer it approached an hyperbola, therefore it cannot be expected that the lines *n* and *m* will be parallel or appear concentric like arches struck from the same centre, but those that should think it disagreeable for the margin of an arch to be wider at top, may easily prevent it by making the moulds parallel to the inward arch, which would be a matter of indifference in respect to its strength.

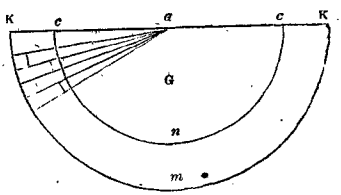


Fig. 423.

"But, notwithstanding all those distant appearances before-mentioned, that are made by the catenarian line, yet I cannot help thinking that they are all of the hyperbola kind, for as the hyperbola is that section of the cone cut any where when parallel to its axis, I say, that it is no hard matter to imagine a cone large enough that will admit of the flattest as well as the highest arches to be cut off by such a section; now, I believe it will appear from what I have already said, that catenarian arches are the best shape for duration, and for that reason the most proper form for the new bridge on the river Thames, if it be built with stone.

"A cask or tub may very justly be said to have the same properties as an arch, for the staves may be considered as so many stones, whose joints point to one common centre, and the hoops that circumscribe them as their weight or pressure; then I think it cannot be denied that the tighter these hoops are drove on round such a vessel, the more compact it must keep the staves, and the stronger the vessel will be for such a weight or pressure; therefore it appears to me that weight on an arch will have the same effect as a hoop hath on a tub, if the weight be well proportioned.

"But in order to give my opinion in this affair, the actions of gravity on solid bodies ought to be understood, and the shape of the arch well considered before a judgment can be formed about the weight it will carry, or on what part to bestow it to the best advantage; therefore I shall lay down the following theorems: —

"I. When any weight presses on the sides or haunches of an arch, the weight on the crown must be considered as an abutment to that weight on the haunches, and in proportion to the height they rise from the chord lines of their respective segments will the weight on the crown be required.

"II. And as the weight on the crown is an abutment to the weight on the haunches, so is the weight on the haunches an abutment to the weight on the crown.

"III. And as the weight on the haunches wants to reduce the curvature thereof to a straight line, contrary to that doth the weight on the crown want to make it rise higher or push it out at foot, if there is no abutment placed there to prevent it, and both would produce that effect if it was not for a counterbalance of power, as will be best explained by the following figure.

"If the segment *a e c* will bear five hundred weight, the semicircle *a b c* will bear six with the same abutment, and the catenarian *a d c* will bear the weight in respect to the abutments below, but if they are both considered as having no weight on their haunches, the catenarian must be the strongest by reason that the curvature of its haunches are nearer a right line than those of the semicircle, for was there as much weight laid on the crown of the catenarian arch as it would just bear, the same weight if applied to the semicircle would occasion it to burst out and fall down, which plainly sheweth that the semicircle wants a greater weight on its haunches to counterbalance the same weight on the crown; and how much more weight is required on the haunches of the semicircle to counterbalance the same weights on the crowns of both may be nearly discovered by the same method, for drawing the chord line *o*, will cut off one haunch of both, which may be considered as whole arches, and the difference of weight be discovered in the same manner, for if the haunch of the catenarian requires nine hundred weight, the semicircle will require

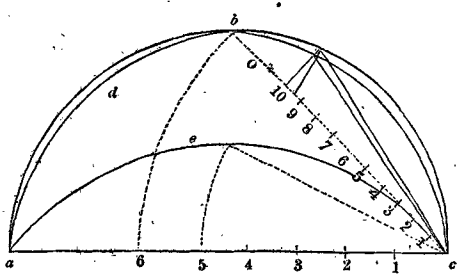


Fig. 424.

ten, to enable it to support the same weight on the crown as the catenarian, and the haunch of the segment *a e c* is likewise subject to the same rule, and requires but seven, by reason the haunch is not so much elevated, which gives the weight a greater gravitation.

"In like manner may the difference of weight be discovered in any two arches, which will always be in proportion as the chord lines of their respective segments are to one another, or in proportion as the sides of the inscribed pediments are to one another, which implies the same thing. To shew the application of the steelyard to the nature and properties of the arch, let *a b c* represent the arch proposed: now if we suppose that the half arch *b c* was in one stone, and its weight 28½ tons, and that it was by some power to be lifted upon its pier *w*, until it come to its centre of gravity, which may be supposed to be at *d*, then it is very plain that the pier must bear all its weight, and if from thence it was to be let down to a horizontal position as at *x*, and a support put under the end at *o*, the support *o* would bear 14¼ tons, and the pier *w* would bear the same weight; and was it from thence to be lifted up to its proper place at B and there supported, then will the pier *w* bear 20¼ tons, and the support at B bear 8¼ tons, for the end B being elevated, the support *o* is released of 6 tons weight, which consequently must be added to the pier, for as this half arch is supposed to be in one stone, it may be considered as a lever, and be subject to the same laws of gravitation as hath before been demonstrated, and may be explained by the figure.

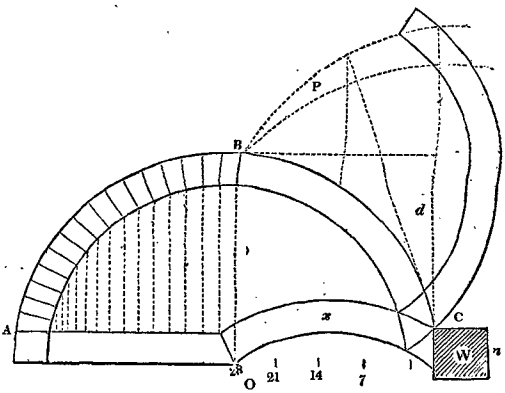


Fig. 425.

"This method seems to me to give some insight whereby the real weight of the abutments may be discovered; for if the support *o* was taken away, and the other half arch, A B, was set up against it, in its proper position, that must certainly throw the whole weight of both on their respective piers; but as A B is set at the same angle as B C, they would thrust each other down, if there was not an abutment placed at A and C to prevent it. Now, if we consider that before A B was set up against B C, the support *o* supported 8¼ tons, the thrust of A B must be equal to that weight, if there was no friction at *c*; and if so, it appears very plain to me, that a weight of 8¼ tons, placed at A and C, will be a sufficient abutment for the arch, A B C; for as such a weight is a counterbalance to the thrust, there will be the friction of A B C on the piers, for a further security; which, considering the great weight of A B C, may perhaps be equal to 2 tons more, but this must be referred to experiment.

"And if the arch A B C was to be considered in parts as the half A B, the weight or pressure would still be the same; for drawing parallel lines, from the joints to the chord lines, plainly sheweth how the weight is diminished, as appears by the figure. By what I have endeavoured to demonstrate, it appears very plain, that the centre which is to support the arch, A B C, will be released of 12 ton weight, in the thickness of the whole breadth, which is supposed to be 40 feet, and the number being multiplied by 12, the product is 480, which being deducted from 2320, which is supposed to be the weight of the whole, the remainder is 1840, which will be nearly the weight, when that of the key-stone is deducted out, that will lie on the centre, before it can be relieved by the keystone. How much of the spandrills' weight will press on the arch is very difficult to discover, because it hath a communication with the upper pier or breast-work, which takes off a great deal of the pressure; but if that communication be destroyed, and it be considered as one stone, and no friction on the arch, it could then be only said to lean on the arch, and what weight that leaning is may in some measure be discovered by the same rule as the former; that is, to draw a line as *d*, in such a manner that if the spandrill was lifted up on its lower point, until that line become perpendicular, it would then be the centre of gravity, and if the line *d* was continued to cut the arch P, and from thence let fall a perpendicular to the chord line, which if divided according to the weight of the whole spandrill, it will give the weight that will press on the arch if the line *d* be so drawn as the quantity of matter on both sides are equal, which ought to be regarded in the half arch, B C, as well as in the present case.

"This method will not exactly discover the weight or pressure of any arch, but it will be

near enough, I believe, to let a man know what he is about when he either designs or erects one.

"In respect to arches, their strength doth not so much depend on their shape, as the weight they bear being well adapted to them; for although it must be granted that catenarian arches, if considered independent of any weight but their own, are the strongest of all others, yet if the weight on their crowns is not proportionable to the height they rise, they may be said to be weaker than a semicircle, or arches of any other form, when their weight and abutments are well proportioned."

Westminster Bridge was the commencement of an entirely new system for laying foundations in deep water, as well as the construction of centres for arches required to span great rivers. An act of parliament for its erection was passed in 1736, and another fixing its site, two years afterwards. The first design was a curious wooden structure, by Mr. James King, resting on stone piers.

The two large middle piers were contracted for soon after, and the wooden superstructure was to have been placed upon them and completed in a year after all the piers were finished, for the sum of 28,000*l*.

Mr. Charles Labelye, a native of Switzerland, presented to the commissioners, in 1738, a design for a stone bridge, which was approved of, and preferred to many others, and it was resolved that the piers should be erected as high as the springing of the arches, viz. about a foot above the level of low water mark, and over these broad piers, smaller ones of solid stone, each to be the width of the bridge in length.

The design for the stone bridge consisted of thirteen semicircular arches, springing about a foot above the level of low water mark; the middle arch 76 feet span, and the others decreasing in width equally on each side by 4 feet, the two next the middle arch being 72 feet wide, and so on to the least of the large arches, which are 52 feet wide. The two small ones nearest the abutments are 25 feet wide.

The length of every pier is 70 feet from point to point, and each end terminates with a salient angle. The two middle piers are 17 feet wide at the springing of the arches, and the others decrease in breadth equally on each side by 1 foot, the two next the largest being 16 feet wide, and so on to the two least of each side, which are 12 feet wide at the springing of the arches.

The piers are 4 feet wider at their foundations than at their top, and each of them is laid on a strong grating of timber, the same shape as the pier, about 80 feet long, 28 feet wide, and 2 feet thick.

The depths and heights of every pier are different, and none of their foundations are at a less depth than 5 feet under the bed of the river, nor at a greater than 14 feet. This difference of depth is occasioned by the nature of the ground, for although all the piers and abutments are laid on a bed of gravel, which on boring was found harder as the depth increased, it was still more difficult to penetrate on the Surrey side than on the Westminster.

In July, 1738, Labelye, with a company of London masons, arrived at the Isle of Portland, and commenced quarrying and working into proper scantling all the stone necessary for the two largest piers. About the same time the carpenters began to make and erect on the Surrey shore twelve frames of timber, supported in a vertical position, parallel one to another, and kept in their proper places by short piles driven into the ground. These frames reached about 2 feet above the common high water mark, and were braced together so as to be kept upright and steady, till the caissoon should be formed and finished on the top of them. The ground sills or bottom pieces of these frames were made cylindrical, that by taking the braces away they might serve as so many axes or centre pieces, round which the frames could revolve all together, for the lowering or launching of the finished caissoons at high water without danger of racking or straining.

In September the engine for driving the piles, which was contrived by Mr. James Vauloüé, a watchmaker, was completed, and on the 13th of that month the first pile was driven.

The piles were of fir, 13 or 14 inches square, and 34 feet in length, shod with iron: round their tops were thick iron hoops, which were taken off after driving, and used again; they were driven 13 or 14 feet below the surface of the bed of the river, and were placed about 7 feet asunder, in lines

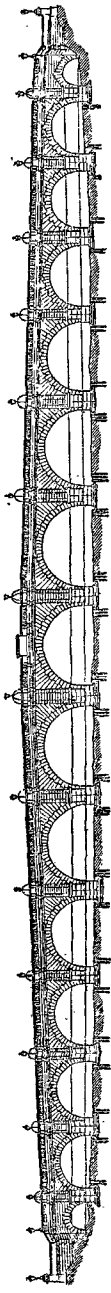


Fig. 426.

parallel to the two short sides of each end of the piers, and about 30 feet distance from them; the use of which fenders or guard piles was to secure the works from the approach of barges; the smaller boats were prevented passing between the piles by booms or long pieces of timber, which floated up and down with the tide alongside the piles, to which they were fastened by wooden rings, and proper iron work. By means of these booms the boats and vessels were secured from damage during the progress of the works.

By the 26th of October, 1738, all the piles necessary for building the two middle piers were driven, and were found to stand so firmly, that the plates, whale pieces, ties, and braces, originally intended to be introduced were omitted. The number of piles used for building the first large pier was thirty-four long and twenty-two short ones; and for the other large pier twenty-six long ones only.

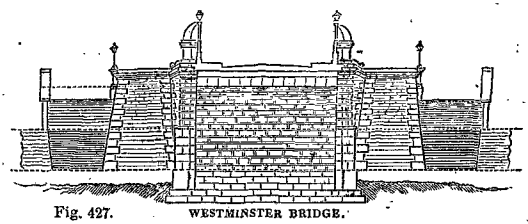


Fig. 427. WESTMINSTER BRIDGE.

The engine employed to drive the piles had a ram or weight of 1700 lbs., and the height of the strokes at a mean was 20 feet perpendicular: with two horses, it gave 48 strokes per hour, and with three horses, 70 strokes per hour. When it had worked sufficiently long for the gudgeons

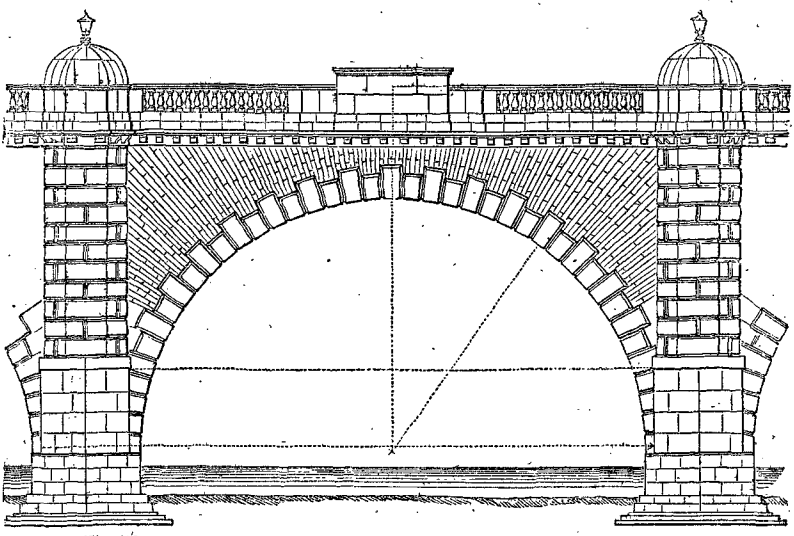


Fig. 428. WESTMINSTER BRIDGE.

or pivots to be rubbed smooth, and the stiffness of the ropes destroyed, three horses, going at a common pace, gave 5 strokes in 2 minutes, on the ram being raised from 8 to 10 feet.

At the commencement of October, the grating for the first pier was finished, and the sides of the caissoon were placed upon it; these were made of fir timber, laid horizontally and close, one over the other, pinned with oaken trunnels, and framed together at all the corners of the caissoon, except the two points or salient angles, where they were secured by proper iron work, which being unscrewed permitted two halves to be removed from the caissoon, which were planked across the timbers, inside and outside, with 3-inch planks in a vertical position; their thickness being 18 inches at bottom and 15 inches at top, and for further strength, every angle but the two points had three oaken knee timbers, properly bolted and secured. The bottom was formed of squared timbers, planked on the underside with 3-inch planking, and across the upper was laid timber 9 inches square, making the entire bottom 2 feet thick.

The length of each caissoon from point to point was 80 feet, the breadth 30, the height, including the thickness of the bottom, 18 feet, and the form that of the intended piers; it contained 150 loads of timber, and in capacity was equal to a man-of-war of forty guns.

After the pier was built sufficiently above low water, and the masons could work with-

out it, the wedges being drawn up, liberty was given to clear the straps from the mortises, when the sides by their own buoyancy quitted the grating under the foundation of the pier.

The sides of the caissoons were prevented from being pressed inwards by means of a ground timber or ribbon, 14 inches wide, and 7 inches thick, pinned upon the upper row of timber of the grating, which exactly filled the space contained between the sides of the caissoon and the first course or lower plinth of the stone pier; and the top of the sides was secured by a number of beams laid across, which also served to support a floor, on which the masons and labourers stood to hoist the stones out of the lighters, and lower them into the caissoon.

In October the ballast men commenced making the excavation for the westernmost of the two piers; when they dragged and excavated a pit 6 feet in depth, of the shape of the

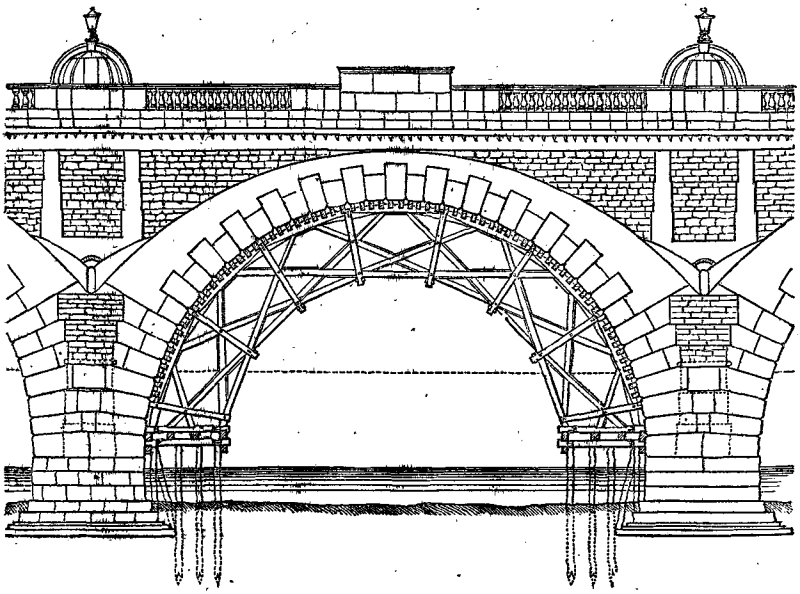


Fig. 429. WESTMINSTER BRIDGE.

caissoon, and 5 feet wider all around, with a slope of such a form that the ground would not fall into it; short grooved piles, reaching 4 feet above low water mark, were also driven before the two ends, and partly along the sides of the intended piers, parallel to the fenders

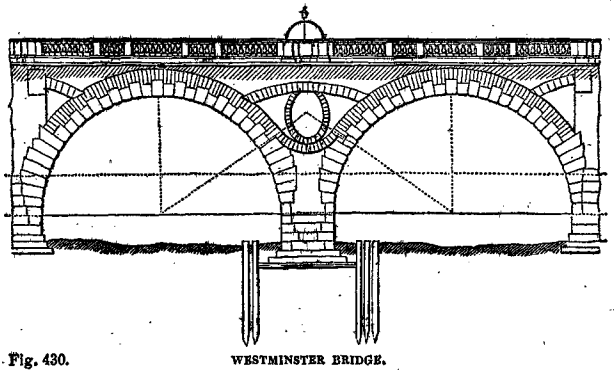


Fig. 430. WESTMINSTER BRIDGE.

or guard piles, and at a distance of 15 feet from the sides of the caissoon, to prevent any silting. Two rows of boards let into grooves were also applied between these piles.

Gauges formed of flat stones, 15 inches square, and 3 inches thick, with a wooden pole

or stem fixed in the middle, 18 feet in length, divided into feet and inches, were used to examine the level of the bottom, and to ascertain if the bed was ready to receive the caissoon.

The caissoon being finished, with a sluice towards the bottom, all the seams well caulked, and the bottom and outsides pitched over, on the 15th January, 1739, it was launched and fixed in its position, by means of a lighter that had been previously moored 200 feet distance from the shore; from the head and stern of which two cables passed to the two ends of the caissoon, guiding its motion, after it was launched, without any person on board to direct it.

The masons then began hoisting the stone into the caissoon, and as soon as the first course was laid, the gate of the sluice was raised near the time of low water, and the caissoon was sunk to ascertain how it sat and grounded. Some loose stones having fallen in, the sluice was again shut, and after two hours' pumping, the caissoon floated; the ground was again levelled, and two days afterwards it sunk to its proper bed when it was a second time raised, and after the masons had cramped the stone of the first course, and set and cramped the second course, the gate of the sluice was raised, and the caissoon sunk, when it was found to bed itself, and set perfectly level on the hard gravel. The water was then pumped out of it, and it floated as before.

The third course of stones being cramped, the caissoon was sunk for the last time; the stone-work of this pier was brought up within 2 feet of the common low water mark. About two hours before low water, the sluice was let down, and by the help of four pumps of 8 inches square, three men to each, and a small spare pump of 3 inches in diameter, worked by one man, the water was pumped out without waiting for the lowest ebb of the tide, for the masons to set and cramp stones of the succeeding courses; before the tide had again flowed or risen sufficiently high to endanger the caissoon and stone-work, the masons desisted for that tide, and the sluice was again opened. By the masons working at every low water, night and day, the first course of the solid shaft was finished by March 24th.

The sides of the caissoon were floated off over the sides of the pier on the 30th March, and applied to the caissoon of the other large pier.

When this was done, the masons placed their crab or engine, with which they hoisted the stone, on a temporary floor, fastened to some fender piles, which guarded the north point of the pier.

On the 20th April the last stone of the torus or cordon was cramped, when the sheers and the crab, as well as the other necessary apparatus were taken away, and the first pier was so far completed.

This new method of building piers having succeeded so well, the commissioners contracted for the two abutments, including the two small arches and the two abutment piers close in-shore, and it was decided that the wooden structure might be dispensed with.

In April, 1740, the masons' work for the three middle arches was contracted for by Andrew Jelfe and Samuel Tuffnell, who had already built the pier.

Mr. James King also contracted to supply the three centres, and subsequently five others, his design for them being preferred by Labelye to his own.

The Portland stone was brought by sea upwards of 250 miles, and the Purbeck from Sandwich in Dorsetshire, a distance of 220 miles. The moorstone was from Devonshire or Cornwall, and the Kentish rag from Maidstone.

The soffite of every arch is turned, and built quite through, the same as in the fronts, with large Portland blocks, over which, bonded in with the Portland, is another arch of Purbeck stone, 4 or 5 times thicker on the reins than over the key.

The breadth of the Thames where the bridge is built is 1220 feet. The length of the two abutments is 226 feet, the section of the twelve piers 174 feet, and the span or opening of the thirteen arches 800 feet, the voids or water-way being double that of the solids.

The breadth of the bridge is 44 feet, which was also the clear width of way at the top; the parapet walls being fixed over the sally or projection of a cordon or rustic cornice, which serves also as a weathering to the stone work.

The road-way is 30 feet in breadth, and each foot-way 6 feet. Over each pier are recesses for shelter. The piers are terminated by a right angle at each end. The spandrills of the arches were filled in with regular rubble stones, with proper bond, and the joints of the work preserve a tendency to the centre.

The entire construction of this bridge occupied 11 years and 9 months; it was completed the 10th day of November, 1750, and the total sum expended upon it is said to have been something under 400,000 pounds. Some delay occurred from the unequal settlement of one of the piers, occasioned by the removal of some gravel from the bed of the river intended for the roadway of the bridge; this took place near the third pier on the western side of the centre arch; the gravel slipping from under the platform, in consequence of the hole made below the foundations, the pier sunk so much that it was necessary to take down the two arches which rested upon it.

On the pier being examined, it was found to have settled 18 inches at one end, and that

it was loaded with 700 tons; after casing it round with strong piles, to prevent a further slipping of the gravel, it was taken down to the level of low water, and rebuilt; to lighten the work which rested upon it, arches were constructed in the spandrills.

Bridge over the Taaf, near Llantrissart, in South Wales, was commenced in 1746 by William Edwards, a country mason; it consisted of three arches, and was admirably executed; two years and a half after its completion, it was carried away by a flood, and as the builder had engaged to maintain it for seven years, he commenced rebuilding it. The second bridge was of one arch, the span or chord of which was 140 feet, its height 35 feet, the segment being that of a circle of 175 feet; the breadth is 15 feet, and the thickness of the arch 2 feet 6 inches. When completed, with the exception of the parapets, the thrust was so great that it pressed in the haunches, and the middle of the bridge sprung up, when the key-stones were forced out. This second misfortune did not quell the courage of our mason, and he undertook his task a third time.

In each of the haunches he introduced three cylindrical holes through the whole thickness, and by this means so reduced the weight that no farther danger was anticipated. The holes or cylinders rise above each other, ascending with the form of the arch; the diameter of the lowest is 9 feet, the second 6, and the uppermost 3 feet; this was finished in the year 1755; the chord line and versed sine were the same as those of the second bridge which fell four years before; besides the cylindrical holes, the spaces between them were left hollow, and filled up with charcoal.

The fame of this latter work spread far and wide, and Edwards was employed to build the bridge at Usk in Monmouthshire, another of three arches over the Tawy, and Pont ar Tawy, over the same river, ten miles above Swansea; this had but one arch, its chord being 80 feet; over each haunch was one cylindrical hole.

Bettws Bridge, in Caermarthenshire, consisting of one arch 45 feet span.

Londonvery Bridge, in the same county, with one arch 84 feet in the span, and one cylinder over the haunches.

Wychbree Bridge over the Tawy, 2 miles above Morriston, which has one arch, 95 feet span, 20 feet in height, with two cylinders over the haunches to relieve them.

Aberaven Bridge, in Glamorganshire, consisting of one arch, 70 feet span, 15 feet high, but without any cylindrical holes.

Glasbury Bridge, near Hay in Brecknockshire, over the Wye, which consisted of five arches.

Edwards, born in 1719, was the youngest son of a farmer residing in Glamorganshire, and some of his first works in the art of construction were the stone walls for the inclosure of the lands on which he was employed; they were so well built, that they attracted considerable attention. An opportunity being afforded him of seeing the tools used by the regular masons, he procured some of them, and commenced squaring the stone for building a workshop, which was so well executed, that it met with the approbation of all who saw it, and it is said that he there introduced the properties of the arch. His first bridges, consisting of only one arch, were evidently too high, which he avoided by flattening the arch, as he became better acquainted with the subject; he proceeded, however, with caution and judgment, having no other guide than his own experience, and he at length learnt that where the abutments are prevented from spreading, arches of little rise are perfectly secure.

As the Castle of Caerphilly was in the parish in which he lived, it is more than probable he derived all his knowledge of construction from that ruin, all his masonry, and the manner of hewing and dressing the stone, being so similar to what he doubtless admired there.

The science of bridge-building had already considerably advanced, and various ideas were then published on the form of arches, in which the merits of the circular, elliptical, and cycloidal curves were discussed. The elliptical seems to have been considered as possessing particular advantages for forming the intrados of an arch, as at its springing the curvature was more considerable, and it rose more perpendicularly, affording an extensive and commodious opening for vessels to pass; and towards the summit or crown the curvature decreased, so as to form almost a horizontal line, which was the best adapted for the roadway; on this account it was probably preferred for some of the bridges afterwards constructed. The cause of the stability of an arch was not at this time sufficiently understood, nor had the engineers given attention to the subject of increasing or decreasing the depth of the voussoirs, or what constituted the absolute weight to be provided for in the abutments: it was not then the practice to consider, that for an arch of equilibration it was necessary to have the curvature of the intrados different from that of the extrados; the principles of the catenarian had not been applied, but in the course of a few years it was generally adopted by our most celebrated builders; and the laws which nature has laid down prescribe the form to be given to the extrados of an arch intended to be lasting. Dr. David Gregory had, in the Philosophical Transactions for 1697, stated, "that none but the catenary was the figure of a true legitimate arch, and that when an arch of any other

figure is supported, it must be because in its thickness some catenary was included;" notwithstanding, no attempt was yet made to introduce its form into the arches of bridges, nor had the cathedral vaulting been sufficiently noticed by our engineers.

Blackfriars Bridge.— During the time that the improvements of London Bridge were carrying on, the Common Council undertook to open a new and magnificent entrance into the centre of the metropolis, by a stone bridge at Blackfriars. After discussing this project for several years, it was at last referred to a particular committee, and a report was made in answer thereto, in September, 1754; this was followed by a design, made by Mr. Dance, the surveyor to the city works, the estimate for which was £185,950, exclusive of purchases of property, and if the foundations for the bridge required piling, the cost would be increased.

The City afterwards applied to parliament, and obtained an act to erect a bridge, with a grant of a reversionary toll, and a power to borrow £160,000 upon the credit thereof. This act was passed in the year 1756, and two years afterwards, twelve aldermen and twenty-four commoners were appointed to carry the same into effect. Designs were afterwards advertised for, and on the 4th of October, 1759, many drawings and models were received by the committee; objections were made to the form of the arches in the design presented by Mr. Robert Mylne, as deficient in strength and stability, which objections were ordered to be laid before eight gentlemen of the most approved knowledge in building, geometry, and mechanics, for their opinion and advice. In February, 1760, their opinions were delivered in, and it was then determined that Mr. Robert Mylne's design should be adopted.

The proceedings of the commissioners for Westminster bridge were then consulted, and the committee advertised for proposals, which were to be accompanied with a specification of different prices for peace and war, a caution never before practised, but by which a saving was made of £5,839.

After the proposal had been received, and all duly examined, the masons' work was given to Mr. Joseph Dixon, the carpenters' work to Mr. John Spencer, the smiths' work to Mr. Bryant, and the ballast work to Mr. Cox and three others.

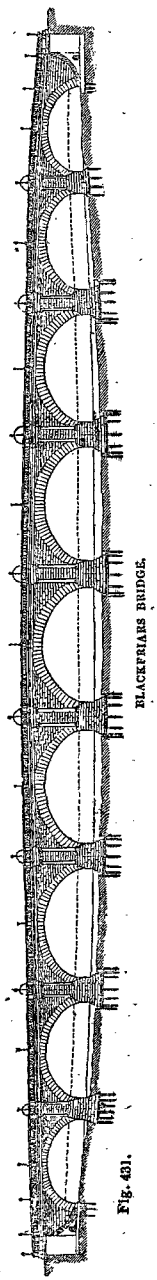
In forming the contracts particular care was taken not to admit a doubt, about either the manner of execution or payment; explicit rules were laid down for the admeasurement of every species of work; the first stone was laid on the 31st day of October, 1760.

A careful examination was made by boring for the foundation of every pier, and the piling was in proportion to the respective textures and solidities, the architect having convinced the committee of the practicability of driving piles under water, and of cutting them level with the bed of the foundations, by an invention of his own.

In fixing the position of the bridge, it was desirable that two objects should be obtained; one, that its direction across the river should be at right angles with the streams of ebb and flood, the other, that its situation, with regard to the bed of the river, should fully answer the purpose of navigation. The great inequality in the bed of the river, where the depth of stream was thrown towards the Surrey shore, made it expedient to place the great arch nearer the latter than the former, as otherwise most of the arches on the London side would at low water have stood upon dry ground, and a great part of the bridge would have been rendered useless to the navigation, and in consequence of this position being taken, the northern abutments were extended to a greater length than the southern.

As soon as a part of the bridge was passable, a temporary arrangement was added, by which the public were enabled to cross, and the toll received was added to the building fund.

In December, 1770, the surveyor applied by a memorial, as the bridge was nearly finished, for the monies due to him to be settled and paid; and the committee, after several days' consideration, determined that he was entitled to receive a commission of five per cent. on works done, of one per cent. on purchases made, being the same as allowed at London Bridge.



BLACKFRIARS BRIDGE.

Fig. 431.

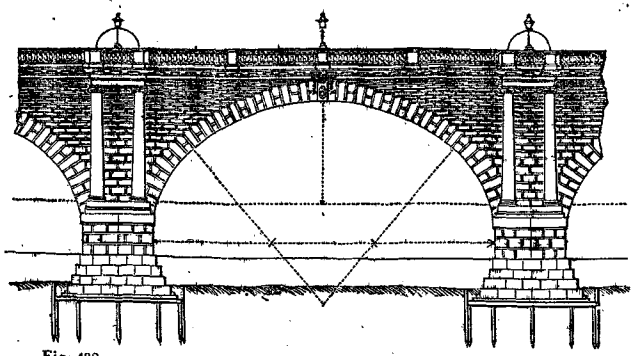


Fig. 432. BLACKFRIARS BRIDGE.

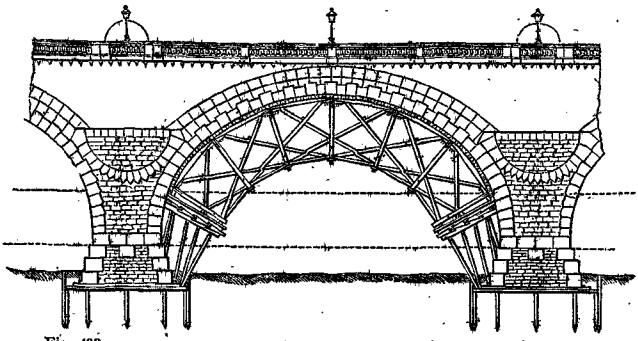


Fig. 433. BLACKFRIARS BRIDGE.

The total cost for the building and completing Blackfriars Bridge, and making the avenues thereto, was as follows: —

	£	s.	d.	£	s.	d.
To Joseph Dixon, mason				111,569	2	8¼
To Dixon and Spencer, carpenter				35,844	8	5
To Messrs. Cox and Co.				10,687	16	7
To William Bryant, blacksmith				3,555	11	4
To sundry other artificers				9,194	14	11¼
				170,851	13	11½
Surveyor's commission of 5 per cent. on all artificers' bills, and 1 per cent. on the purchases and sales of premises	9130	1	0			
5 years' salary for his constant attendance on the meetings of the committee, and for inspecting and taking care of the bridge, streets, roads, sewers, new buildings, and various matters relating thereto, from 1 June, 1773, to 1 June, 1778	525	0	0			
By salaries and gratuities to the clerks of the committee from Michaelmas, 1758, to Michaelmas, 1778	1683	2	6			
By ditto to the chamberlain's clerk, for keeping the accounts from Michaelmas, 1760, to Christmas, 1777	693	15	0			
By ditto to the hall keeper and his man for summoning the committee from Midsummer, 1759, to Michaelmas 1776	433	0	0			
				12,464	18	6
Incidental expenses				4,507	8	8
Interest paid on £144,000				25,920	0	0
Purchase of ground and premises				35,584	1	11
Cash to Watermen's Company for the purchase of the Sunday ferry				12,250	17	6
Total				£261,579	0	6½

The bridge consists of nine elliptical arches; the middle one is 100 feet span, and the others decrease gradually to 98 feet, 93 feet, 83 feet, and the two outer ones each 70 feet, leaving a clear water-way of 788 feet. The breadth across the bridge is 43 feet 6 inches, and the total length from wharf to wharf is 995 feet. The breadth of the carriage-way was 28 feet, and that of the footpath on each side 7 feet; this, however, has recently undergone considerable alteration, and the effect of the original design is entirely destroyed. The piers were built in caissoons, like those at Westminster, but previously to their being moored and placed in their respective situations, the whole of the space to be occupied by them was closely piled over. They are smaller in proportion to the arches than those of Westminster bridge, and the whole work shows that considerable advances had been made in buildings of this character. The Ionic columns resting on the piers, which diminish in height, taking the curvature of the roadway, have been censured, but there is much to admire, if we take into consideration the period of its erection. The caissoons were made of fir timbers, as were all the piles; the sides and bottom of the former were constructed like those at Westminster, but their form was rectangular; their length was 86 feet, their breadth 33 feet, and their entire height 29 feet. The sides were secured to the bottom by strong iron straps, six on each side, and three at each end, 20 feet in length. At one end a portion about 10 feet was hung on short hinges, and a floor at 16 feet from the bottom served to brace and secure the sides, and to receive the machinery which worked a chain pump. Level with the top was a similar floor, on which was placed the capstan for lifting the stone; there was also a triangle for the same purpose, and a windlass for lifting the mortar. Four upright pieces of timber were secured to each side of the caissoon, which, with the assistance of barges, enabled them to be removed. When the stone-work was built up to the level of low water, a barge was laid alongside, and fixed to the upright pieces, so that when the tide raised the barges they lifted up the caissoon, care being taken to disengage the long iron straps and the movable piece at one end; and when the caissoon was sufficiently raised to clear the bed of the river, it was floated off. The height of the caissoon rendered barges necessary, particularly as all the machines were attached to the upper floor.

Many stone bridges were erected in England during the eighteenth century, some of which exhibited considerable talent, particularly those executed under the directions of Mr. Gwynn, a native of Shrewsbury. Kew, Maidenhead, Henley, and Oxford had stone bridges over the Thames, but one of the boldest designs was by Sir Thomas Robinson, who, in 1762, constructed a single arch at Winstone, over the Tees, with a span of 108 feet 9 inches; the versed sine being 45 feet, the diameter of the circle of curvature at the vertex 112 feet, and the height of the key-stone 3 feet.

The bridges built by John Smeaton do not display any boldness of design, nor remarkable science in their construction; we have already noticed much that he performed for the improvement of our harbours, and also his great undertaking and masterpiece, the Eddystone lighthouse. This celebrated man, and perhaps first practical civil engineer in England, was born at Austhorpe, near Leeds, on the 28th of May, 1729; he very early displayed a fondness for mechanics, and at twenty-one we find him employed as a mathematical instrument maker. About 1750 he transmitted to the Royal Society an account of the improvements in the mariner's compass by Dr. Knight, and two years afterwards he furnished the same society with those he had made on the air-pump, and an engine for raising water by fire, a subject upon which the French philosophers were then busily engaged: he was soon afterwards admitted as a member, when he introduced his ideas upon the pyrometer, and several other subjects. About this period he was induced to travel into Holland and the Netherlands, where he had the opportunity of examining the system of draining and management of locks on the canals, and several important engineering works then progressing under the direction of very able men: and on his return to England he occupied himself in inquiries relative to the powers of water and wind, on their application to machinery, where circular motion was required; and after great patience and labour he was enabled to exhibit their results to the learned men of the society in several models of undershot, breast, and overshot wheels, which he accompanied with calculations of their relative value: the novelty as well as utility of his observations obtained for him the Copley gold medal, and, what was far more important, he was selected as the builder of the Eddystone lighthouse by the Earl of Macclesfield, who was then president. We have already seen with what diligence he set about preparing himself for that great work, and how ably he accomplished the very arduous and difficult task: after its completion, the public seem not to have encouraged his talent as he merited, for we do not find him employed again until 1761, when he was associated with Mr. James Brindley in surveying for several canals in Staffordshire. Among his reports dated after this year are some on canals, improvements of rivers and harbours, draining, and a description of many useful inventions and applications of foreign methods for constructions in water. His reports are exceedingly valuable, and show that he was admirably qualified for all he undertook. He was a great observer of nature, and applied his mind diligently to examine her works;

when called upon to shorten the course of a river, or improve its channel, he directed his attention to the causes which had produced the results he was required to amend. This eminent engineer died the 16th of September, 1792, to whom we are indebted for many improvements in air and water-mills; before his examination into the force of water, our machinery was in a very rude state; he called forth the inquiries from which the present generation are now reaping advantage.

Bristol Bridge.—When Smeaton was consulted upon the rebuilding of this bridge in 1762, he observed, that no limit was yet fixed for the span of arches, or the proportion of their rise, since the widest and flattest that had been attempted upon right principles had succeeded as well as the narrowest and highest, provided the abutments were good, and the stone and cement of a firm texture.

One of the peculiarities in this engineer's designs was that of perforating the spandrills of his arches by a circular opening, and also employing segmental or elliptical arches in preference to semicircular. The skill with which he managed his centres cannot be too highly admired; the strength is always greatest where most required, and there is no unnecessary quantity of timber made use of. Of the various bridges that are mentioned in his reports are those of Perth, Stoneham Creek, Glasgow, Dumbarton, Old London, Howick, Aberdeen, Edinburgh, Coldstream, Newcastle, Hexham, Berwick, Banff, Dumballock, Braan, Altgran, Bewlie, Conon, Sutton, Walton, Harraton, Carlton Ferry, and Montrose, and others, several of which he entirely rebuilt. The utmost span given to his arches was 75 feet, the width of the piers being made about a fifth; the same proportions we shall find at Perth bridge, which he built about the time that Blackfriars was completed.

Bridge over the River Tay, at Perth.—In 1763 Smeaton was consulted by the justices of the peace for the county on the practicability of building this bridge; and, after the necessary surveys, he gave a design for one of stone, having seven principal arches, extending 605 feet 9 inches, and in the whole length 893 feet. The width is 22 feet in the clear between the parapets; the span of the two outer arches 70 feet, the next 72 feet 10½ inches, the next 74 feet 6 inches, and the centre arch 75 feet, leaving a water-way of 509 feet 9 inches. The piers of the middle arch were in width 17 feet, the other four isolated piers each 16 feet. An estimate accompanied the design, supposing the foundations to be laid 8 feet under the bottom of the deepest part of the river, which was based upon the information he had received, that there was a stratum of hard gravel 8 feet below the bed of the river, upon which the piers were to be placed, without either piles or grating. The river at its ebb had not more than 2 feet depth of water, and at ordinary spring-tides did not rise more than 8 feet above this mark, and he considered that a dam capable of keeping out the water 4 feet above its low state would enable the men to work nine or ten successive days between each spring-tide; and that a dam of this height was not only less expensive in its construction, but also less likely to be injured, than another raised high enough to keep out the spring-tides. A sluice made in this dam let the water in and out, and it was so formed, that a clear space of 16 feet was left round the pier for the convenience of the workmen. The dam was elliptical, the better to resist the tides and floods.

Cofferdams, materials in, and cost.	£	s.	d.	£	s.	d.
26 gage piles, of 10 feet long, at 10*s.*	13	0	0			
2328 feet supl. of plank piling, 9½ feet long, at 1*s.* 2*d.*	135	16	0			
122 feet cube of timber in strong pieces for supporting the pile heads, at 3*s.*	18	6	0			
Extra work to sluice for letting in and out the water	2	10	0			
Timber work in one cofferdam				169	12	0
To pile shoes for 26 gage piles, at 1*s.*	1	6	0			
To plank pile shoeing 245 running, at 6*d.*	6	2	6			
To 25 bolts for the string pieces, at 2*s.*	2	10	0			
To extra iron work about the shuttle, and contingencies	2	0	0			
Iron work about one cofferdam				11	18	6
A cofferdam complete				181	10	6
A cofferdam complete				181	10	6
The materials for the first pier are supposed to be of half value towards each succeeding pier, which will therefore be No. 6, at 90*l.* 15*s.* 3*d.*				544	11	6
Cofferdams for the whole				726	2	0

	£	s.	d.	£	s.	d.
Excavation and Drainage.						
To excavation of the matter, 722 yards for each pier, at 6*d.*	18	1	0			
To drawing off the water, supposed equal to 50 days, at 20*s.* per day per pier	50	0	0			
	68	1	0			
The excavation and drainage of six piers, the two abutment piers, and foundations for the wing-walls, being supposed equivalent to two piers, the whole will be equivalent to eight piers, at 68*l.* 1*s.* each				544	8	0
Masonry in the piers and abutments, below the springing of the arches.						
To 1080 feet supl. of ashler in each pier below water, at 7*d.*	31	10	0			
To 1176 ditto above water, at 8*d.*	39	4	0			
The whole pier in solid contains 467 cube yards, including labour, carriage, tarras mortar, six inches in the outside joints, and all materials, at 5*s.* per yard	116	15	0			
N. B. The ashler being at least 20 inches bed, and cubed into the solid, at 5*s.* per yard, is supposed to pay for the tarras mortar and extra labour in setting thereof.						
To capping the pier with solid blocks, jointed between the springer stones, 600 cube feet, at 6*d.*	15	0	0			
To capping the ends of the piers, 148 feet supl., at 8*d.*	4	18	0			
To six piers and two abutment piers, each reckoned as a pier, that is No. 8., at 207*l.* 7*s.* 8*d.*	1659	1	4			
To walling in the west land stool, to bring it up to the springers to be at a medium 5 feet thick, containing 490 cube yards, at 5*s.*	122	10	0			
To hammer-dressing that part of the wall that comes in view below the plinth, containing 666 feet supl., at 1½*d.*	4	3	3			
To working the plinth, being before reckoned as solid, containing 990 feet supl., at 3*d.*	12	7	6			
To 78 cube yards of masonry, in the east land stool, to bring it up to the height of the springers, at 5*s.*	19	10	0			
To setting under the west abutment arch, to prevent the water from affecting the foundations, 1353 feet at 4*d.*	22	11	0			
Masonry in the piers, and abutments below the springing of the arches				1840	3	1
Centering for the arches.						
To timber in one rib 416 feet cube, and for six ribs	2496 cube ft.					
To timber in 30 bearing piles and 5 capt-trees, for supporting the ribs	750					
To stays and braeings between the ribs to keep them upright	75					
To covering for the centres in square scantlings	525					
To additional work to make the centres fit the large arches	188					
To timber in a centre complete	4034 at 3*s.*			605	2	0
To iron work in the six ribs, 1852 lbs. at 5*d.*	£38	11	8			
To ditto in pile shoes and hoops, 662 lbs. at 5*d.*	13	15	10			
To spikes, nails, and other contingent articles	5	0	0			
The iron work for one centre				57	7	6
One centre complete				662	9	6
To a set of piles and cap pieces, ready prepared for driving in the second arch before the first centre is struck, containing 750 feet, at 2*s.*				75	0	0
To 5 booms, containing 375 feet of timber, at 2*s.*, to be fixed as struts between the piers of the second arch while the centre is taking down from the first and putting up in the second				37	10	0
To taking down the centre, drawing the piles, driving ditto, and setting up the centre 6 times, repairing and making good what is wanting, at 9*d.* per cube foot upon the timber, which being 4034 feet, comes to 151*l.* 5*s.* 6*d.* each time, and for 6 times				907	13	0
Taking down and putting up the booms 5 times, at 6*d.* per foot				46	17	6
To centering for one of the small arches, at 20*s.* per square				20	0	0
To taking down, removing, and setting up ditto in the other arch				5	0	0
Centering for the bridge complete				1754	10	0

	£	s.	d.
Masonry in the superstructure.			
To 15,850 feet supl. in the soffite of the main arches, being 3 feet thick, set in place and mortar included, at 20*d.*	1320	16	8
To 2000 feet supl. in the soffite of the abutment arches, at 1*s.*	100	0	0
To blocking up the spandrills of the arches solid 6 feet high, containing 473 cube yards, at 5*s.*	118	5	0
To cube masonry in the spandrill walls, abutments, and wing-walls, from the top of the piers to the top of the cordon, containing 3776 yards, at 5*s.*	944	0	0
To hammer-dressing the plain superficies thereof, containing 33,984 feet at 1½*d.*	212	8	0
In the parapet, 11,856 feet supl. on both sides, being 15 inches thick, stone, workmanship, mortar, and setting ditto, at 6*d.*	269	8	0
To 18,382 feet supl. in the faces of the arches, bands and keys, the cordon, mutules, capping, and pedestals, which being before reckoned in solid, except their projecting parts, and all square work, at 4*d.*	306	7	4
To 2160 feet supl. in the 12 eyes, and 640 feet in the terminating pillars, in the whole 2800 feet supl. of circular work (being before included in the solid), at 6*d.*	70	0	0
The walking path, being 4 feet wide, contains 3641 feet supl. of stone, working and laying, at 7*d.*	106	12	0
Masonry in the superstructure	3447	17	0
Gravel.			
To 10,948 cube yards, to fill up the spandrills and wing-walls, and form the road, at 9*d.*	410	11	0
Contingencies.			
To piling engines, pumps, and other utensils, supervisal, unforeseen accidents, and expences	1000	0	0
Abstract.			
To cofferdams	726	2	0
Excavations and drainage	544	8	0
Masonry in the piers and abutments	1840	3	1
Centering for the arches	1754	10	0
Masonry in the superstructure	3447	17	0
Gravelling the bridge	410	11	0
Contingencies	1000	0	0
Total	£9723	11	1

In the batterdeaus and centres there remained at least 5763 cube feet of timber, which if sold at 9*d.* per foot cube would amount to 214*l.* 2*s.* 3*d.*, besides iron work, engines, and utensils; which, it was presumed, would be sufficient to make the road to and from the bridge.

The prices in the preceding estimate include all labour, carriage, mortar, and setting up in place, unless otherwise particularly expressed.

Description and method of fixing the foundation of the second pier and the cofferdam. — The gravel proving harder than was expected in this last pier, much time being occupied in driving the piles of the cofferdam down to their proper depth, and so much difficulty being experienced in drawing them, that they were severely injured when drawn, it was proposed that for this pier there should be as many additional piles, as should set the whole at the distance of 9 feet from the sheeting of the base of the pier, and that they should be driven no further than to fix them firmly in the ground, even should that happen at only 2 feet.

To prevent the filtration under the bottom of the piles, gravel and corn-mould earth were thrown in on the outside, after being well mixed together; and this was sloped against the piles, and extended to a width of 6 feet all round.

Method of forming the excavation. — The pumps being fixed, and the water pumped out, the excavation was made to the size of the pier; and after having got down a space in the middle to its proper depth, the width and depth were increased, till the area was clear for driving the piles, upon which the foundation frame was to rest, and no more, leaving the matter on the outside of the area to form its own slope towards the cofferdam, so that the rest of the area remained solid, to support the sheeting of the dam.

The depth of the excavation was determined after the following rule. It must be excavated at least 3 feet at a medium below the natural surface of the gravel where the pier stands; but if this did not carry down the base of the pier within 2 feet of the level at which

the base of the first pier was fixed, the depth of the excavation must be increased, till it is within 2 feet of the former depth.

Method of fixing the foundation according to the plan. The excavation completed, let the 21 piles upon which the frame is to rest be driven into their proper places; these piles are to be 10-inch heads, and 6 feet long, supposing the gravel of equal strength with the last; the pile heads are then to be reduced to a level, and the frame laid thereon; and trenailed down upon the pile heads. Then the sheeting piles are to be driven; and these may be of oak, elm, beech, or fir, and about 6 feet in length, as these piles are to be rebated, and if possible driven without splitting.

To save timber, it was recommended to groove the piles on both sides, and to nail in the tongue, which might be of hard wood if fir piles were used; these tongues were to be 1½ inches in thickness, and 1¾ inches broad; and to be let in ¾ inch where it fastens, and to stand out 1 inch. The tops of the sheeting piles, being reduced to the same level as the string pieces to which they were to be spiked as they were driven; the outside was to be reduced to a regular breadth, and the notched stones taken in a line. When this was performed, the rest of the bearing piles were to be driven, beginning with the outside rows, and cut to a level with the tops of the string pieces; the piles were to be 6 feet, more or less as found requisite.

The setting was to be completed by first underpinning the string pieces and tie-beams as firmly and equally as possible, by driving stones under them, and then the other spaces to be set and well driven down as before; but before ramming down, the joints were to be filled, by sweeping in dry lime mixed with sand and small gravel, so that the whole when driven down should be thoroughly compacted together.

After the pier was raised above low water, the matter was to be taken out 4 feet in width all around, down to the level of the top of the notch course, and then filled with good lagging as before, standing somewhat higher than the natural bed of the river, and the rest of the space covered with rubble to the sides of the dam.

The bearing piles were to be driven until the ram made them descend 1 inch for every 20 blows, and the sheeting piling, until it required 40 blows to drive the same quantity; and the latter were to be driven to a regular depth throughout.

Coldstream Bridge over the Tweed, designed in 1763 by John Smeaton, has five arches. That in the centre is in span 60 feet 8 inches, the two adjoining 60 feet 5 inches, and each of those on the land sides 48 feet. They are all parts of the same circle; the smallest arches being one-third, and the others rising higher in proportion to their span. The height of the piers above low water, including the impost, which is 2 feet, is 12 feet precisely, so that the shaft of the piers before the impost was put on is 10 feet.

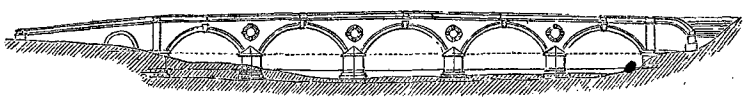


Fig. 434. COLDSTREAM BRIDGE.

The engineer in one of his reports upon this bridge remarks, that he found the gravel of the Tweed lie very open, and not wrecked up with sand and matter in the usual manner, and though generally objecting to piling foundations, which are tedious and expensive, and getting down to the rock, would from the nature of the gravel make the drainage exceedingly so, he in this case recommended piling the foundation 3 feet below the bed of the river; in general he observes that in similar cases it was usual to lay down a grating and build upon it without any piles at all; but that here the floods might take away the gravel and leave the grating bare, which would eventually undermine the pier; and that to defend the foundations in the usual way, by building starlings round the piers, terminating above low water, would also be objectionable, as the water-way would be too much contracted.

Hexham Bridge, as designed by John Smeaton, had nine elliptical arches of different spans, and extended 518 feet between the abutments, and 568 feet comprising them; the width measured on the soffite 20 feet, and the clear between the parapets 18 feet.

The span of the centre arch was 51 feet, the piers 12 feet 6 inches; the adjoining arches 50 feet 7 inches; the piers 12 feet; the next arches 49 feet 11 inches, the piers 11 feet 6 inches; the next arches 48 feet, the pier 11 feet 6 inches, and the two outer arches span 37 feet. This bridge, which was destroyed by a flood in 1782, was a considerable loss to the contractors. Five of the piers were built in a caissoon, the internal width of which was 16 feet, the length on the flat side 22 feet; the bottom was formed of 3-inch plank laid crosswise, and the sides of 3-inch plank placed upright, supported by three ribs of timber, two on the inside and one on the out, all secured at the angles by iron bolts in a proper manner.

On the upper rim iron studs were screwed, over which an iron chain could be cast when the caissoon was moored, a pile being driven above and below bridge for this purpose.

All the joints of the planking and sides, and the cross and upper planking of the bottom were grooved about $\frac{3}{4}$ inch in depth; and a lath $1\frac{1}{2}$ inches in breadth, and $\frac{1}{3}$ inch thick, was let into it with tar; and over the joints was nailed a strip of thick flannel covered with tar, 3 inches in breadth upon the outer edge.

During the excavation, the floods carried away the gravel under the caissoon, the fourth pier from the south abutment settled about 18 inches; in many places, the gravel was removed to the depth of 30 inches, and several of the stones were driven out of the cutwater of the pier.

This damage was remedied by enclosing the several foundations with a row of sheet piling, which prevented the gravel from further washing from under the base of the piers; and then filling up the cavities below the bed of the river with rough rubble stones, and the inside of the piles with smaller quarry rubble and clean sand, in the proportions of 2 of stone to 1 of sand.

To underpin the piers effectually, it was necessary to make use of a diving machine, the principal part of which was an air-chest, 3 feet 6 inches in length, 4 feet 6 inches in depth, and 2 feet in width, provided with a copper air-pump which threw in a gallon of air at a stroke; it was sunk with the proper tackle, by attaching 16 pigs of lead to it.

A board was put across for a man to sit on, with another for his feet, and a pane of glass inserted at top to admit the light.

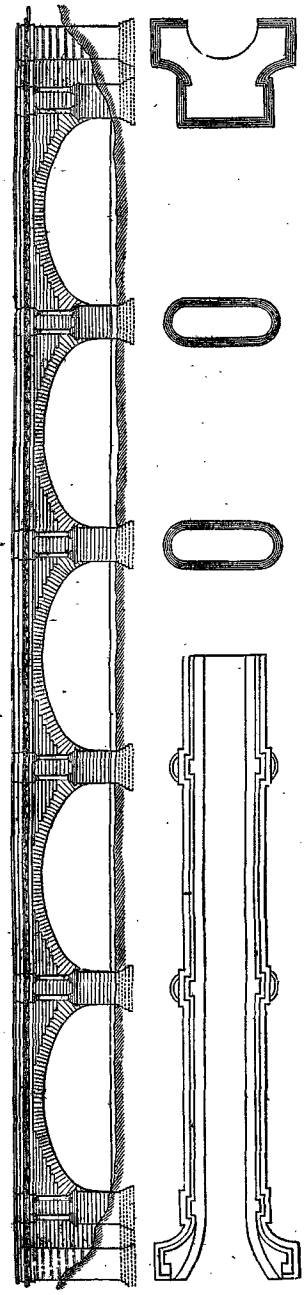
The pump was formed of a copper cylinder 10 inches in diameter, and 12 inches high; wired at top, and a flanch at bottom $1\frac{1}{4}$ inch broad, by which it was screwed down to the top of the air-chest; the copper is described as being the thickness of a halfpenny. The sides of the air-chest had $2\frac{1}{4}$ plank for the ends and bottoms, and $1\frac{3}{4}$ inches for the sides.

Kelso Bridge, over the Tweed, consists of five arches, each 72 feet span, with a versed sine of 20 feet 9 inches; the diameter of the circle of curvature at the vertex being 114 feet.

This beautiful work, completed by Mr. Rennie about the year 1799, was the model for Waterloo Bridge; the estimate for its construction was 12,876*l.*, which was not exceeded.

The old bridge at Kelso was constructed of six semicircular arches, with a water-way of 318 feet, where the river was 561 feet in width.

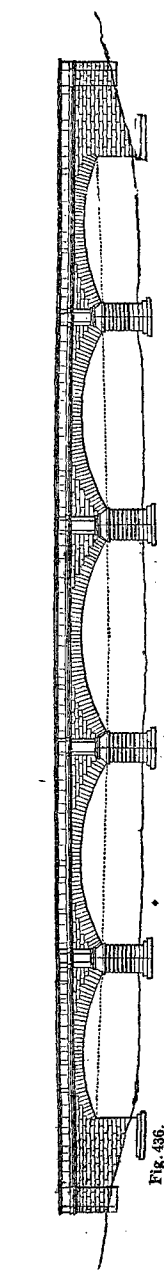
The roadway of this bridge is perfectly level; over each pier are two columns, which sustain an entablature that runs the entire length; these columns project about three quarters of their diameter, and are of graceful proportions. The width of the bridge measured on the soffite of the arches is 26 feet. The scenery around this structure is admired for its beauty, and the conflux of the Tweed and the Teviot rivers is enriched by the engineer; at the period this bridge was constructed, similar works were carried on in France, but none excel this example in simplicity or style of execution. The objections made to the introduction of columns at the bridge of Blackfriars do not hold good in the Kelso Bridge, for they are of one proportion throughout, and are not diminished in height towards the abutments to adapt them to the curvature of a cornice, which rakes with an inclined



BRIDGE AT KELSO.

Fig. 435.

roadway; there can be no doubt, however, that it would have been better to have omitted the columns altogether, as they can hardly be supposed fit decorations for the piers of a bridge.



BRIDGE OVER THE RIVER CREE.

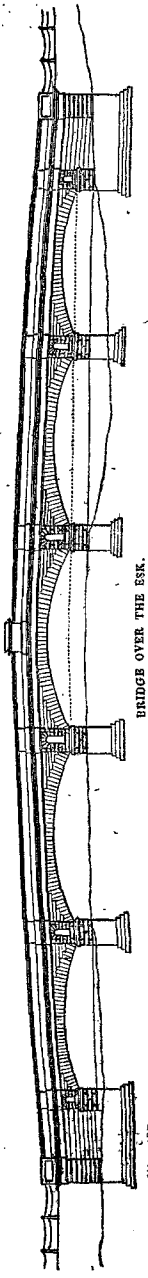
Fig. 436.

Bridge over the River Cree at Newton Stewart, executed also by Mr. Rennie, consists of five arches, all segments of circles; that in the middle is 50 feet span, with a versed sine of 6 feet 6 inches, its two piers are 8 feet in thickness; the arch on each side of the centre is 46 feet span, with a versed sine of 2 feet 9 inches, and the outer piers are diminished in width 6 inches; the two arches on the land sides are 39 feet in width, with a versed sine of 4 feet 9 inches.

The roadway, which takes the same curve as the cornice of the bridge, is 20 feet in width between the parapets.

Bridge over the Esk at Musselburgh was also constructed from designs by Mr. Rennie, about the year 1803. It consists of five segmental arches of considerable radii; that in the middle is 45 feet span, with a versed sine of 6 feet 6 inches; the arches on each side of the centre are 42 feet span, with a versed sine of 5 feet; the outer arches, or those adjoining the abutments, are 37 feet span, with a versed sine of 3 feet. The piers are all 7 feet in width above the set-off, and are rusticated to the underside of the cornice, which has a circular form, and follows the curvature of the road.

In the bridges over the Cree and Esk the flat segmental arches produce the most elegant and pleasing effect. Ammanati, in his beautiful design executed at Florence (Fig. 184.), had already shown how much grace could be obtained by the introduction of arches that approached the elliptical form. Perronet, some years afterwards, also with great success, adopted others which formed a portion of the circle, or were very flat curves. St. Maxence on the Oise (Fig. 280.), and Brunoi on the Hyeres (Fig. 282.), executed by that celebrated engineer, served as models for many executed in France; among which may be reckoned that of Jena at Paris, erected in 1808 by Lamande (Fig. 288.); but all these bridges, though their arches are of an increased span, and of bolder construction, do not surpass the examples we are describing. The curvature given to the roadway, to accommodate the level of the banks of the river, differs from the French examples, but is admirably accomplished in the Kelso bridge, where the effect is improved by the cornice being maintained horizontally throughout. The enormous sums of money that have recently been expended to lower the crowns of Westminster and Blackfriars bridges, so as to render the draught over them less laborious, ought to satisfy those who are partial to a curved line of road, that utility and elegance equally recommend its discontinuance; and that, wherever a level surface can be obtained, without too much increasing the expense of the abutments, it should be adopted. Independent of this the eye is better satisfied with such an arrangement, as the ends of the bridge, where all the strength is required, gain importance by elevating it above the ordinary level of the shore, and an idea is conveyed of power to resist the combined thrust of the arches, by the additional loading it receives from the increase of height. A reference to Waterloo Bridge will convince the most fastidious that the level line not only possesses the greatest convenience, but beauty also; the latter arising out of the fitness of the several parts for the uses to which they are devoted.



BRIDGE OVER THE ESK.

Fig. 437.

Stoneleigh Bridge, in the county of Warwick, was constructed by Mr. Rennie. It is built of stone, and the centre arch is 92 feet span, with a versed sine of 13 feet. The abutments are solid, and very ornamental; they have an opening in the middle of each 12 feet wide, with a semicircular head. The Doric entablature, which runs through the

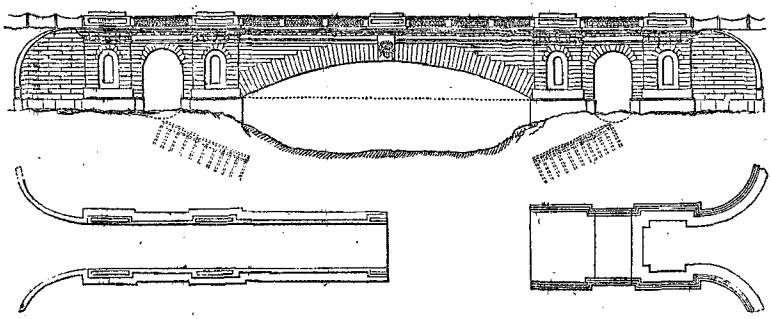


Fig. 438. STONELEIGH BRIDGE.

entire length of the bridge, has a good effect; it is surmounted by a balustrade, and the roadway is kept horizontal.

Wellington Bridge, over the river Aire, at Leeds, erected under the direction of Mr. Rennie. It spans the river where it is 100 feet in width, and the banks 8 feet in height. The arch is the segment of a circle, 91 feet radius, with a versed sine of 15 feet. Coffer-dams were made use of to construct the abutments, which were protected by sheet piling and wales; each of these abutments is in length 30 feet, and 28 feet in width at the bottom, diminishing by offsets to 27 feet in length and 21 feet in width where the arch springs. These abutments are built with radiating courses within, but on the face they are horizontal, and the stones used are from 14 to 18 inches in thickness, and were accurately cut from templates made to suit each course. All the lower courses of the footings were laid without mortar, but had their joints well grouted; the others, up to the water-line, were laid in mortar, made from magnesian limestone; the proportions used were, one of lime, one of clean river sand, and one of forge scale, well mixed and tempered, and used quite hot. The masonry of the arch was put together with mortar, of equal proportions of lime and sand. After the abutments were completed, the piles were driven to carry the centre, the lagging of which was laid 5 inches higher than the proposed arch, to allow for its settlement. There were six of these ribs or centres, of Memel timber, and the whole contained 2220 cube feet. The striking wedges were of oak, 6 inches in width, and 9 inches in height; the middle one being the largest. The voussoirs in front were 7 feet on the bed at the springing, diminishing to 4 feet at the crown; but the interior arch stones were on an average 3 feet in length, and 18 inches thick. After the arch was turned to the extent of one-third on each side, the centre was loaded at the crown with 20 tons of stone, and the haunches were not further loaded until after the key was placed, which was about three or four weeks from its commencement. The centre was enabled to bear the weight of a thousand tons, yet it was found that the wedges were forced into the timber, and it was necessary to cut them out. The arch, during the progress of the work, was squeezed down 2½ inches, and after the centre was struck another 2½ inches. The stone used was a coarse red sandstone, or millstone grit, from Bramley Fall, a quarry about four miles above the bridge. It was delivered scappled, ready for dressing, at 9*d.* per cube foot; the dressing and setting, exclusive of the cornice, cost 4½*d.* per cube foot, including the mortar 15*d.*, and the cornice and parapet walls about 4*d.* extra. The total quantity of masonry was 80,000 cube feet, and the entire cost of the bridge was 7530*l.*

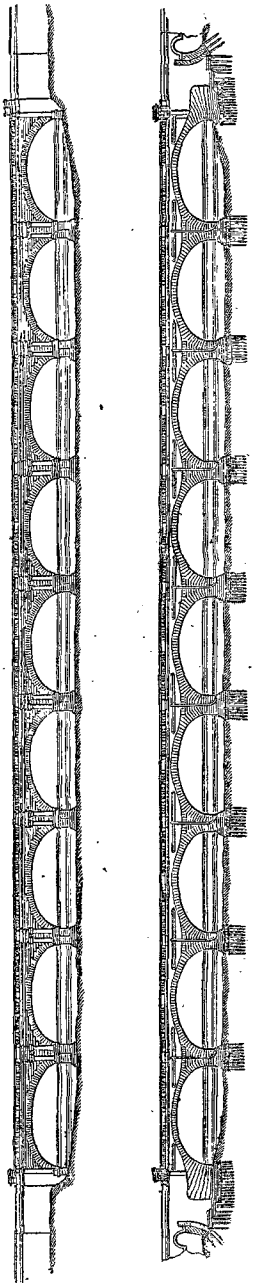
Waterloo Bridge, commenced on the 11th of October, 1811, after the designs of Mr. Rennie, may be considered to form a new era in the art of bridge-building. Caissoons in this instance were abandoned, and cofferdams made use of instead, for laying in the foundations. The width of the Thames in this part is 1326 feet at high water, which is spanned by nine equal semi-elliptical arches of 120 feet opening, with a versed sine of 32 feet, and a rise of 35 feet above the surface water of spring-tides, so that the clear water-way is 1080 feet. The diameter of the circle of curvature at the vertex of these arches is 225 feet, the depth of the key-stone 4 feet 6 inches. The abutments are 40 feet in thickness at their base, and gradually diminish to 30 feet at the springing of the arches, and are 140 feet in length, including the stairs. The piers are 30 feet wide at their base, diminishing to 20 feet at the springing of the arches, and their extreme length is

87 feet. The sides of the bridge are defended by an open balustrade; the carriage road is 28 feet wide, and the footpath on each side 7 feet.

The roadway is nearly horizontal throughout, and level with the terrace at the back of Somerset House. This was nearly the first bridge so constructed, and great credit is due to the engineer in thus triumphing over the vulgar prejudice, that it was necessary to incline the thoroughfares to obtain a greater elevation of the middle arch: in the arrangements at Blackfriars the columns are made to diminish in height towards the abutments; in the present case they are of the same altitude throughout; consequently the entablature is not distorted, and from the excellent effect produced by this level line of cornice being preserved, the bridge is justly considered the most beautiful structure of the kind.

The cofferdams were formed of three concentric rows of piles, placed about 3 feet 6 inches apart; the stratum into which they were driven was gravel; each elm or beech pile was 12 inches in diameter, and about 20 feet in length.

The form given to the cofferdams was that of an ellipsis; and the heads of the piles, after they were driven into the gravel, were cut off, about 5 feet above the level of high water mark spring tides; to secure them more effectually, wrought-iron screw-bolts were passed through them, as well as three rows of waling pieces, the ends of which were covered by stout cleets. Cross and diagonal braces of whole timber connected and strutted the several rows of piles; the dam was braced longitudinally in several places, and struts were introduced in every position where they were not found to interfere with the masons in their work. The water which accumulated or passed into the cofferdam could be let out at low tide by means of a short tunnel formed in the end; and a sluice, moved by iron racks and wheels, enabled the workmen to open or close the mouth of the tunnel at pleasure. The spaces between the piles were filled with well puddled clay, that had been beaten and prepared for the purpose before it was put on board the lighter which conveyed it to the cofferdam. In the execution of this work great attention was paid by the engineer to obtain a perfect command over the water at all times, and thus prevent any interruption to the men employed upon the masonry of the piers, which was completely effected by means of a steam-engine erected for the purpose: neither hand-buckets, pumps and machines worked by men or horses, nor the numerous contrivances described by the French engineers, could have emptied the space comprised within the area of a cofferdam in so short a time as it was accomplished by this; hence the labour was continued almost without interruption, on many occasions being proceeded with for twenty-four successive hours, a most important advantage in constructions of this kind. The application of the steam-engine to bridge-building has wonderfully economised both labour and time; piles are driven, their heads cut off by its power; manual labour has thus been greatly abridged, and the use of horses almost rendered unnecessary; in the present instance, the stone and other materials were so laid upon the temporary platforms or timber constructions, as to be within the command of the power of the engine at all times, and heavy weights were moved by very simple tackle and machinery.



WATERLOO BRIDGE.

Fig. 439.

The arches being all equal, and of an elliptical form, produce an admirable effect; the depth of the key-stone is between a twenty-sixth and twenty-seventh of the span, which is

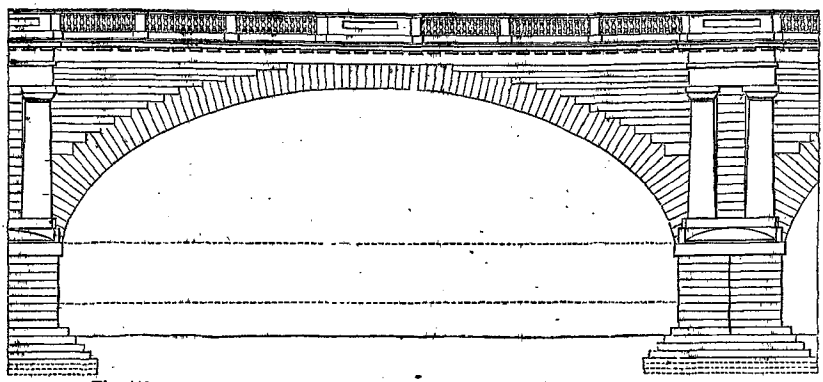


Fig. 440. ELEVATION OF ARCH, WATERLOO BRIDGE.

exceedingly small as compared with all previous examples, and it is no more than a fiftieth of the diameter of its circle of curvature. In the theory of the arch the thickness given to the voussoirs forms the most important consideration; and here we have them admirably proportioned, so as to diminish the pressure on the arch, and increase in strength towards the springing, that is to say, in proportion to the accumulated tangential pressure. At sixty degrees from the top the voussoirs are lengthened, and continue to receive some addition down to the springing.

The bridge at Neuilly, built by Perronet, is at the crown 4 feet 8 inches in thickness, and its span is 128 feet, with a versed sine of 32 feet: the crown of the arch being the portion of a circle whose radius is 150 feet, its horizontal thrust is very considerable, and the key-stone is made 4 feet 8 inches in height; nevertheless, the arch sunk when the centre was struck nearly 2 feet, whilst those of Waterloo descended only a few inches.

The form given to the starlings at Waterloo Bridge is well contrived to split the stream in its current, and carry the water quietly under the arches.

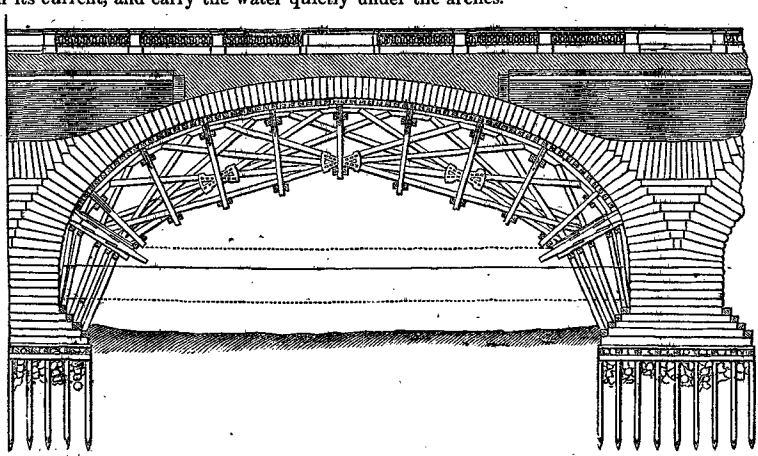


Fig. 441. WATERLOO BRIDGE.

The centres made use of were admirably contrived, and put together in such a manner that they could be readily dropped, if required, by means of the wedges introduced upon the heads of the inclined piles. The piers and abutments being raised to their necessary height, to receive the arches, the timber centres or ribs were set up, framed together, as represented in the elevation of the arch: these centres were remarkable for their strength, and calculated to support the weight of the voussoirs placed upon them, throughout the entire progress of the construction of the arch until finally keyed by the introduction of the last stone. The form of the arches has undergone no change, which is the best indication that can be adduced of the excellent manner in which the centres were framed and supported. They were laid upon whole timbers, which capped the piles; and under each set of ribs the wedges were introduced, which were made to extend across the entire

width; so that when it was required to ease the centre, wedges were driven along each other, and slid down the inclined plane into larger spaces than they had previously occupied: the whole centre, consequently, could by this means be made to descend very gently, and remain so during any part of the operations.

The inclined piles, which carried the weight of the ribs of the centre, had their bearing on the offsets of the stone piers, which afforded a most effectual and perfect abutment; and it must be acknowledged, that the skill shown in putting together a centre of such vast weight and dimensions is a strong evidence that improvement in bridge-building has been greater here than on the Continent.

The section through the piers shows their construction, which is of solid granite throughout; over the spandrills are rows of columns, which carry the roadway, and a pipe conducts the water from the channels of each gutter to an opening immediately above the last set-off, where the pluvial waters are discharged into the river.

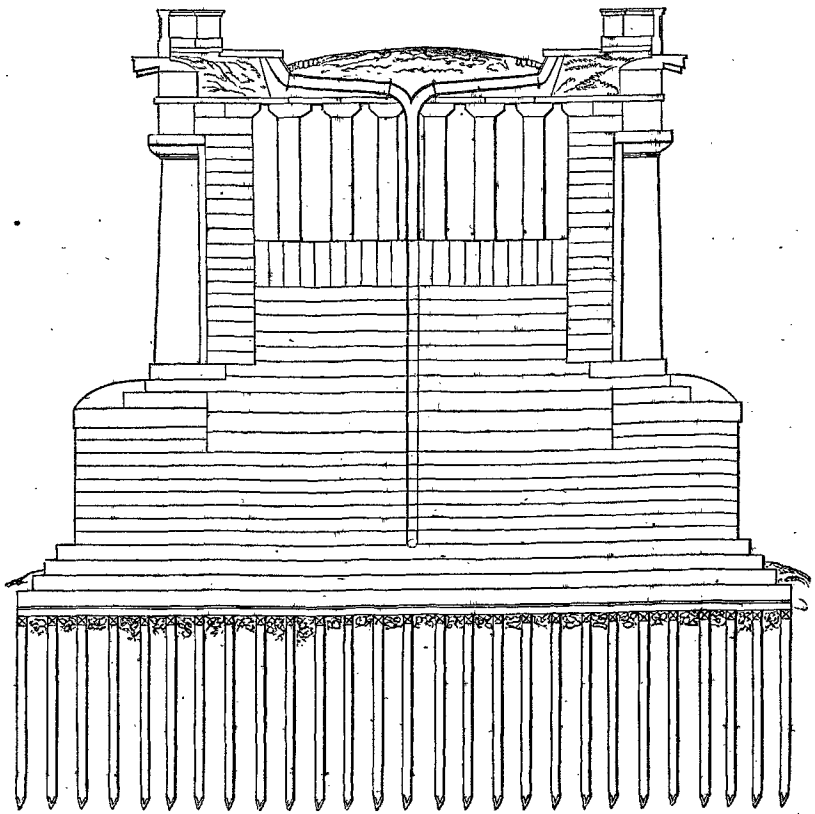


Fig. 442. SECTION THROUGH PIER OF WATERLOO BRIDGE.

Great attention was paid to have the spandrills of the arches constructed with solid masonry, laid in regular horizontal courses, and of one uniform thickness throughout, and where bedded upon the extrados of the arch, they were very carefully worked, so that the whole was made solid and secure: before any course was proceeded with, the last executed was dressed on the surface, and rendered perfectly even, that the layer of fine mortar introduced under the beds should have a uniform thickness: over these were constructed inverted arches, the stones of which increased in dimension with the radius, and these also were carefully dressed, so that they should perform their office effectually, contributing additional strength at the back of the main arches, where these were likely to spring, without adding unnecessarily to the weight on the piers: this feature in the construction of the arches of a bridge was, perhaps, first introduced at Westminster, but was not there so admirably executed as in the present example.

The section through the arch exhibits the twenty-four voussoirs which lock the whole, the top of which is level with the upper portion of the architrave that rests on the two Doric columns.

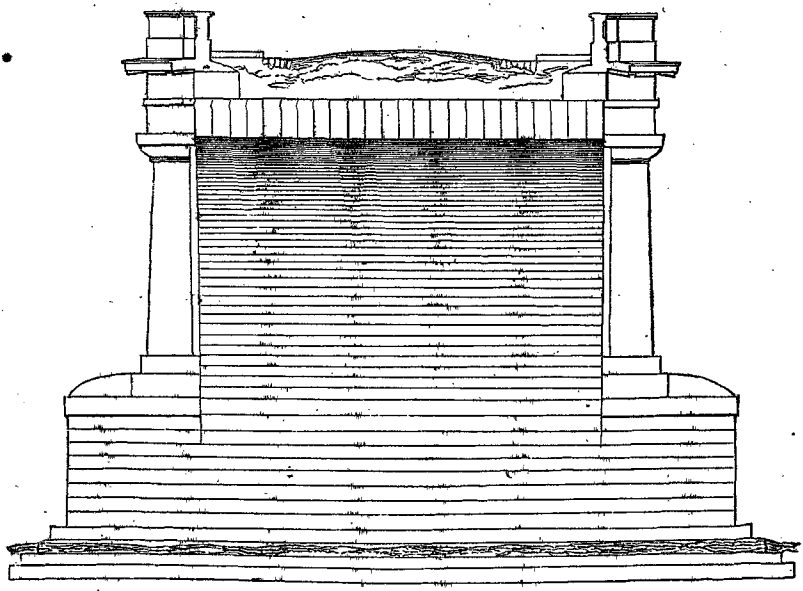


Fig. 443. SECTION THROUGH ARCH OF WATERLOO BRIDGE.

The abutments are of singular beauty, and comprise within them staircases to descend to the river at all times of the tide; from the increase in their width, both above and below

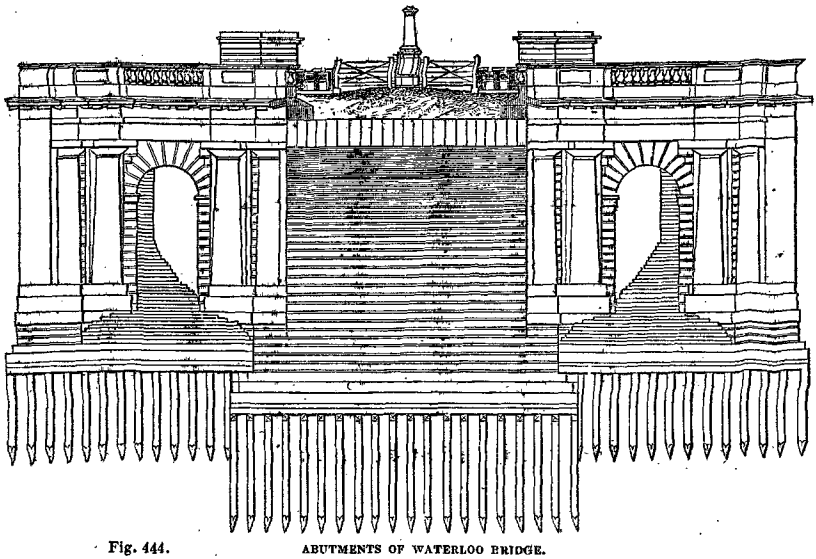


Fig. 444. ABUTMENTS OF WATERLOO BRIDGE.

the bridge, greater security is given to the structure, and the eye is pleased by the additional masonry.

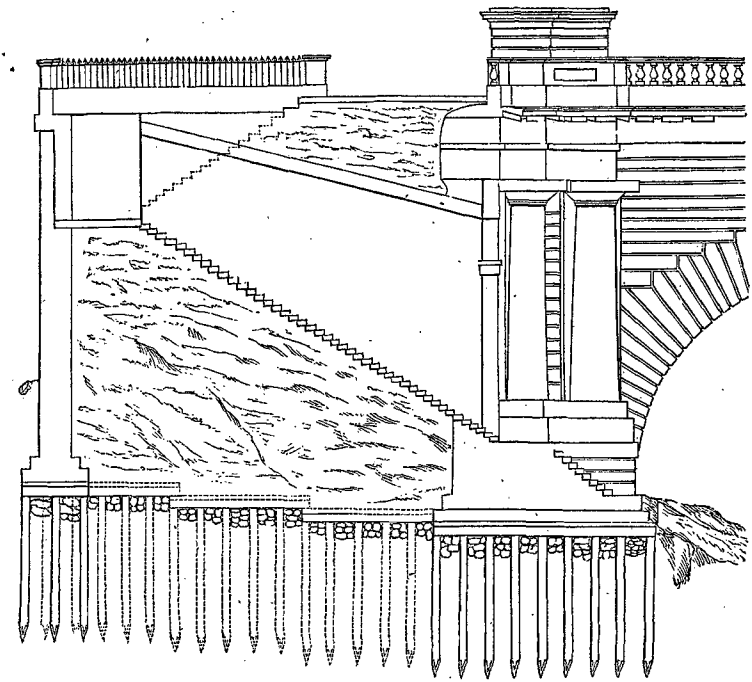


Fig. 445. SECTION THROUGH THE STAIRS OF WATERLOO BRIDGE.

The section through the stairs, arch above, and solid masonry resting on the piles below, give some idea of the precautions taken by the engineer to render his abutments perfectly solid; beyond these, and continuing for an immense distance on the Surrey side, is a series of brick arches, on which the roadway is carried, which gradually inclines towards the obelisk in St. George's Fields. On the Strand side the ground rising rapidly, the same extent of arches was not required.

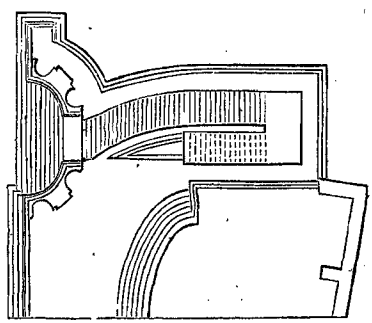


Fig. 446. PLAN OF STAIRS.

"Waterloo Bridge is an imposing and beautiful structure, which has received most unqualified praise from all capable of judging of its merits: as the works were generally constructed in a similar manner to those of London Bridge, it has not been thought necessary to enter more upon them here, but to refer to that specification for further information upon the subject; the whole surface of the piers and abutments, as well as the arches, are of Cornish granite, and the filling in is of Cragleith and Derbyshire stone.

London Bridge, at the commencement of the nineteenth century, was in such a state of dilapidation as to require either that a large sum of money should be expended upon it, or that a new structure should be erected; an application was made to parliament on the subject, when a select committee was appointed to consider what was necessary to be done.

On the 28th of July, 1800, this committee reported, that notwithstanding large sums had annually been expended upon the bridge, the methods hitherto adopted for its security had not proved effectual; that the bed of the river suffered injury from increasing shoals, partly from its natural course being obstructed, and partly from the dispersion of materials employed to strengthen the piers. That the bridge was in such a state that it could not be substantially repaired; that its foundations were daily undermining, from the force of the agitated water rushing through the confined arches; and the committee was of opinion, from the enquiries they had instituted, that the rebuilding of London Bridge upon improved principles would be a measure of economy.

The report made by Mr. Robert Mylne on the state of the River Thames and its bed, on the structure of London Bridge, and the navigation of the river above and below it, in the year 1800, contains the principal information on those subjects furnished to the select committee.

In this report he states, that whilst the alterations were making at London Bridge in 1761 and 1762, and during the removal of the pier under the great arch of 70 feet span, he was consulted by Parsons, the contractor, as to the best manner of performing his contract; and he advised that a hole should be made in the ashler works forming one side of the old pier, on which the two Gothic arches rested, which was to be removed. On examination it was found that the pier rested on four rows of piles, driven closely together round its outer edge; the tops of which were at a very considerable depth below the present low water mark. Around these and forming the starlings were others, which he drew up by means of powerful screws fastened to the heads, and then, by destroying some of the ashler work, he was enabled to displace and draw some of the outside quadruple row, on which the foundations of the pier were laid; the pier quickly became a ruin, and dissolved away in the midst of that impetuous agent, the fall under the bridge. The outer piles being carried away, the heart or middle of the work was borne off so suddenly, as hardly to leave any time to consider and measure its substance and texture. All that could float was dispersed up and down the river; but some of the original piles were preserved, which were stated to have been there about 586 years. The original bed of the river, under the substance of the pier, had never been exposed to such a rapid stream before; it was then much higher in level than any parts above as well as below the bridge; its substance was soon worn away by the powerful friction, and in proportion as the space and depth were enlarged, the violence of the stream increased in power, by the current being drawn from both shores and from the small arches, augmenting the volume of water, which was greater than had ever before existed. This corrosion at both sides of the old pier spread across the bottom of the locks adjoining, and attacked the stability of the starlings under the old piers of the new arch; unfortunately the outer faces of these starlings were so close to the stone piers, and only 6 feet broad underneath the haunches of the great arch, that no pile engine could act, and there was but little space to stand and perform any efficient works. Mr. Smeaton was immediately called in, and he advised the only probable remedy for the urgency of the case, which was to throw as much stone as possible into the vacuities of the foundation, to preserve it from further corrosion; accordingly, the stones belonging to the old city gates, which had recently been pulled down and sold, and which were stored up at no great distance, were repurchased and thrown into the gulf which had been formed from the deep water above to the deep water below the bridge. This remedy seems to have been suggested from the manner in which Gautier states the bridge of St. Esprit to be supported, and maintained at a constant and great expense, yet the whole of the advice was not followed. Increased velocity formed additional danger, and eddies were thus created, in which all sorts of vessels became entangled. After a great deal of discussion, a compromise was effected between those who contended for having the current as gentle as possible under and through the bridge, and those who were for maintaining as strong a current as might be, in order to work the water wheels attached to the bridge. And the report further states, "that if the bridge was totally removed, and nature restored to its full power and original possessions at this place, there cannot be any doubt but the navigation would be here, as at any place upwards to Fulham Bridge, free, open, and unencumbered for all the variety of craft which navigate that extent of the river. Boats would pass up or down against the stream, equally as well as they do now any where else; and a greater quantity of tidal water being admitted, by the removal of that which obstructs its influx at present, the intercourse inland would be enlarged and extended by as much further as the tide would certainly flow. The reflow of that newly and enlarged quantity of water would scour out the sand shoals and muddy shores, and hurry off the filth produced from the common sewers, which through a certain sluggishness in the stream is not cleared away at present. The west country barges, and other large craft, would not be detained in certain parts of the river for want of water in dry seasons. The upper end of the tidal water would swell the natural waters a long way further up, and thereby release the craft from a demurrage, which increases the cost of the voyage,—this question pervading the inland trade as far as Reading and Oxford. If the pass at London Bridge was free, the land floods of the Thames would have a ready passage to the tide way and the sea, and thereby pass off the useless superabundance more readily, and in such a manner that the shores and towing paths would be used, and barges pass more freely under the floors of the scaffold bridges at Chelsea, Fulham, and Kingston. The high waters of the tides respectively would be so much higher in this district, and the velocity so much stronger upwards, that the voyage would be done in less time, and with more safety, through a deeper water at each period of the tide. Some of the walls, it is true, would be found between this bridge and Kew not quite adequate thereto, and would have to be raised by their respective owners."

The area or space of water-way of the whole river at London Bridge before the same was

built was, by Mr. Mylne's measurements, "19,586 feet superficial nearly, taking the width equal to the length of the bridge, and the depth from the face of its bed, underneath the arches, up to the visible marks of the flow of the tide on the modern stone-work. It is reasonable to suppose, the bridge being removed, that would be the space through which the tidal waters would flow. The water-way of all the arches or locks added together, taken from the surface of the starlings (which are 1 foot 10 inches out of a level endways, and not altogether on a level with one another across the river) down to the floors of the locks respectively, was, in 1767, 3530 feet superficial. The water-way of all the said arches above the starlings to high water mark, above mentioned, deducting the triangular spaces at the haunches of each arch, forms a space of 4470 feet superficial. Now, these added together form the whole space of 8005 feet nearly, and this is very much diminished in its powers by being divided into nineteen parts, one very large, and many others exceedingly small. It is further diminished in its effects by stages and piles, stretching 290 feet along the bridge; and by as much as the water-wheels at their periphery do not move so fast as the current of the stream in the face arches, and thereby producing a considerable retardation of the due effect there would be if they were not there. Many of the floors of the locks have been raised to a degree of no small danger, and the outsides of the starling have been covered with planking since 1767, all of which last make considerable deductions from the quantity of 8005 feet; yet if that space alone be deducted out of the area of the whole, there remains of solids in this bridge 11,581 feet superficial. This is nearly a proportion of the solid parts, occupying three-fifths of the river, and leaving only two-fifths for the passage of the whole river."

The water-way at Westminster Bridge was, before it was built, 19,010 feet superficial, and now 14,768 feet, so that the piers occupy 4242 feet superficial only.

The water-way at Blackfriars was, between the present shores before the bridge was built, 19,083 feet superficial; the water-way of all the arches or openings is 15,081 feet superficial, and the piers occupy a space of 4001 feet superficial. The proportions then are as follows:—

	Area of River.	Solid.	Water-way.
London Bridge - - -	19,586	11,581	8,005
Westminster Bridge - -	19,010	4,242	14,768
Blackfriars Bridge - - -	19,083	4,001	15,082

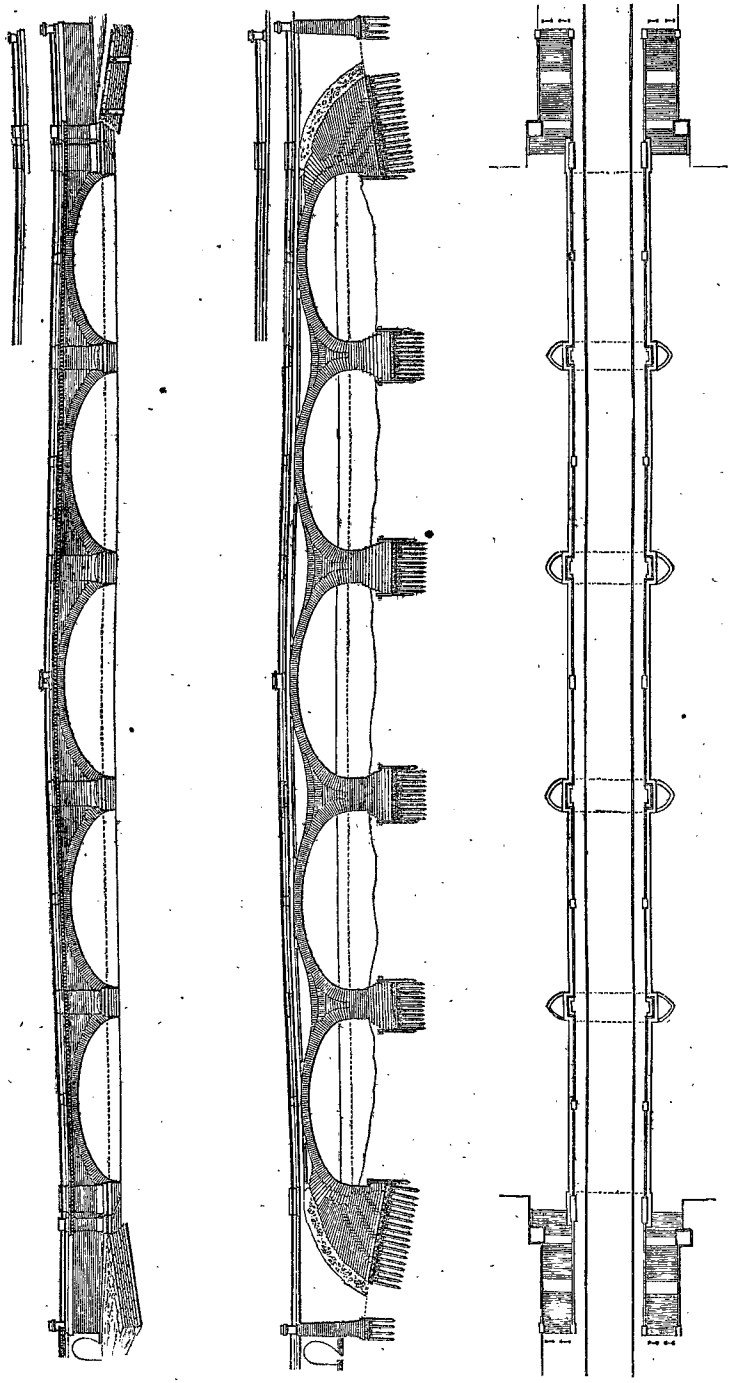
When the committee of the House of Commons had determined upon the erection of a new bridge, Mr. George Rennie, at the desire of his father the late Mr. Rennie, made the design as it is now executed; and as the country lost the services of Mr. Rennie by his death in 1821, the execution of this important undertaking devolved upon his sons, and Mr. George Rennie holding at that time a situation under the government, his brother Sir John, who was his junior, was named the acting engineer. Messrs. Joliffe and Banks were the contractors, and the cost, including the approaches, amounted to £1,458,311 8s. 11¾d. The first pile for the cofferdam was driven on the 15th of March, 1824, and the dam was finally closed on the 1st of April the following year, and after the water had been pumped out 29 feet below low water mark, it was found remarkably tight.

On the 27th of April the workmen commenced their excavations in a stiff blue clay, after which the sills and planking were laid ready for the foundations, which were commenced on the 15th of June: the first stone laid was a piece of Aberdeen granite, 5 feet ⅝ of an inch long, 3 feet 6¾ inches broad, and 2 feet 10 inches deep, containing 50 feet 7 inches cube, and weighing 4 tons.

The cofferdam for the second pier was completed soon after, and pumped out by the 24th of August; in 1826 the foundations on the Southwark side, comprising the abutment and wing-walls, were carried up, and the second pier was commenced.

The coffer-dams of the first and second piers being no longer required, a portion of the piles were cut off on both sides, to prepare them for the support of the centres; and after the horizontal wedges were fixed on the heads of the coffer-dam piles, on the 30th September the first rib was set up by means of large sheer poles and powerful hoisting tackle, and by the 10th November, the whole ten ribs were placed.

When the masonry of the second pier was sufficiently advanced, the centre, which had been framed in the Isle of Dogs, was floated up the river, and being hoisted upon a large double barge, was raised into its place by means of screws, assisted by the tide. The cofferdam of the third pier had by this time advanced, and soon afterwards that of the fourth pier, when it became necessary to provide more water-way by removing the pier between the fifth and sixth locks of the old bridge, and forming a wooden tressel frame of whole timbers for the traffic to pass. This was performed at the cost of 8000*l.* by demolishing one half of the arch at a time, after which the pier below was taken away 4 feet below low water mark. By the 4th of August, 1827, the first arch was completed; by the end of the year the second arch was keyed in, the foundation of the third pier completed, and that of the fourth laid. In 1828, the water being pumped out of the north abutment dam, and the excavations made, the first pile was driven on the 1st of February, and the



LONDON BRIDGE.

Fig. 447.

entire foundations completed on the 1st of March following; the masonry was then carried up to the springing of the arches.

The first arch turned having now stood the entire winter, the wedges were struck 2 inches back on each side, and the crown lowered $\frac{5}{8}$ of an inch; the wedges were then driven back 4 inches more on the following day, when the crown of the arch sank another half inch. On the third day they were driven back 6 inches, when the crown of the whole arch was clear, and shortly after the wedges were entirely driven back, when the soffite of the arch was accurately examined, and found to have preserved its form entire, although it had lowered $1\frac{1}{2}$ inch. By this time the centres of all the other arches were placed, and the masonry considerably advanced: in 1829 and 1830 the centres of the middle, fourth, and fifth arches were shifted back, and when released of their load, the middle arch sank $2\frac{1}{2}$ inches, the fourth $2\frac{1}{4}$ inches, and the fifth $1\frac{3}{8}$ inch.

The centre arch is 152 feet span, and rises 29 feet 6 inches above Trinity high water mark; the arches on either side span 140 feet, and rise 27 feet 6 inches above the same line, and the abutment arches span 130 feet each, and rise above the same line 24 feet 6 inches. The entire water-way being 692 feet, the total length of the bridge 1005 feet, its width from out to out 56 feet, and its height above low water 60 feet. The two centre piers are 24 feet in thickness, and the two others 2 feet less.

So important a national work requires us to enter more into particulars, and to give the specification and forms of the contract, which are perfect models of their kind, and will serve as such for similar undertakings.

"*Cofferdams for the abutments.*—These dams are to be of a circular form, and of the size and dimensions in every respect as shown in the drawings exhibited; they are to be composed entirely of the best Memel, Dantzic, Riga, or Stettin, fir timber. The piles are to be composed entirely of whole timbers, that is, none to be less than $12\frac{1}{2}$ inches square when measured in the work, and as much larger as the timber will allow; the main part of the dam is to be composed of two rows of piles, not less than 5 feet apart, the inner row to be driven not less than 10 feet, and the outer row not less than 8 feet below the lowest parts of the foundations, that is, the square parts of the piles are to be driven to this depth besides the shoes, and when driven, both rows are not to be less than 5 feet above high water mark of spring tides, according to the Trinity House standard. These two rows of piles are to be properly secured together with three rows of double waleing, not less than $12\frac{1}{2}$ inches square each; these three rows of waleing are to be secured together with the best wrought-iron screw bolts, 2 inches diameter, passing through each set of waleings at every 10 feet, and having their ends secured with the best wrought-iron plates, not less than 10 inches long by 8 inches wide, and 1 inch thick, and wrought-iron screw nuts 5 inches square, and 2 inches thick, and wooden cleats not less than $12\frac{1}{2}$ inches square and 3 feet long, the whole to be well fitted and screwed up to their bearings. There is to be a third or outer row of piles, to be composed entirely of whole timbers as before, and to be not less than 6 feet asunder from the main rows of piles; these piles are to be driven not less than 8 feet below the lowest part of the foundation, that is, the square part of the piles are to be of this depth besides the shoes, and their heads are not to extend higher than the level of half-tides, or 7 feet below high water mark of spring tides, according to the Trinity House standard, except that there are to be two piles at such distance as are shown in the drawings, to be of the full height of the inner rows. This outer row of piles is to be connected together with not less than three rows of double whole timber waleings, as before described, and to be connected to the main dam with long wrought-iron screw-bolts, 2 inches diameter, passing through the three rows of piles at each row of waleings, and at the centre of every space between the bolts belonging to the inner rows of piles, and having their ends secured with cleats and nuts as before described, and well fitted and screwed up to their bearings: the whole of the three rows of piles above described are to be planed and straightened on the edges, and the joints of the two inner rows are to be caulked and covered over with pitch, so as to be perfectly water-tight; they are also to be braced firmly together by transverse and diagonal braces, composed of half-timbers firmly fitted and spiked together, and having their ends supported by cleats where required; the whole of the piles are to be properly hooped and shod with the best wrought-iron, and the hoops and shoes to average 56 pounds weight each. The spaces between the three rows of piles are to be well fitted with the best tough well-beaten clay, thoroughly puddled, so as to be impervious to water; the space between the two inner rows of piles is to be filled with the above clay to the level of not less than 2 feet above high water of spring tides, according to the Trinity House standard, and the space between the outer and middle row of piles is only to be filled with clay up to the level of 2 feet below the upper waleing of the second row of piles, and to incline downwards to the heads of the outer row of piles; besides the diagonal and transverse braces above described, there is to be a series of main, transverse, and longitudinal bracings for the interior of the dam; at the level of each row of waleings these transverse and longitudinal braces are to be composed entirely of double whole timbers, firmly scarfed, bolted, and strapped together with the best wrought iron bolts and straps, and supported by piles,

as described in the drawings; the minor transverse and diagonal braces are to be composed of whole timbers only.

" The whole of these braces are to be firmly united together with wrought-iron straps and ties at their ends, in order that their dams may be firm and immovable in every part; there is to be a tunnel, not less than 3 feet square, placed towards the centre of the dam, and at the level of low water mark of spring tides, it is to be secured with a proper sluice worked by machinery, as shown in the drawings, in order that it may be raised or lowered at pleasure; this tunnel is to be properly secured on all sides to the piles, and to have its joints well caulked, so that it may remain perfectly water-tight. There will be two of these dams.

" *Pier Cofferdams.*—These dams are to be of an elliptical form, of the size and dimensions as shown in the drawings; they are to be composed entirely of the best Dantzic, Memel, Riga, or Stettin fir, all the piles to be composed of whole timbers, and none to be less than 12½ inches square when in the work, the main dam to have two rows of piles, not less than 5 feet asunder, and when driven to be not less than 5 feet above high water mark of spring tides, according to the Trinity House standard; they are to be properly secured and connected

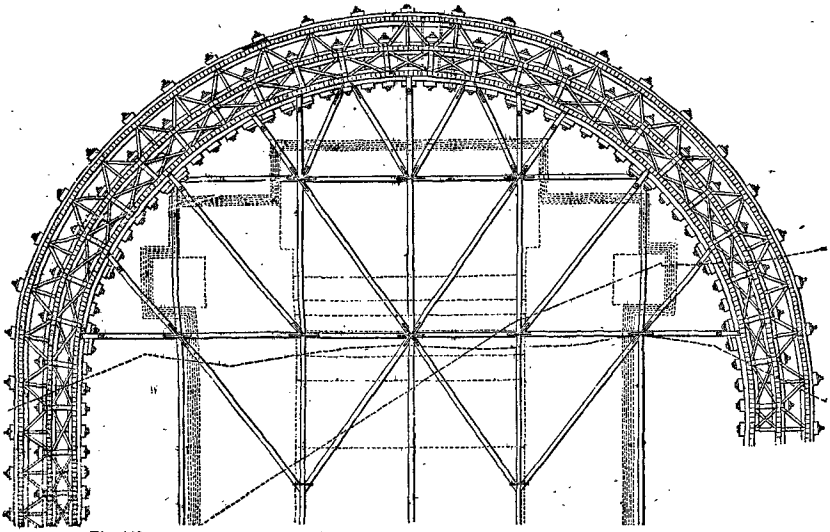


Fig. 448. PLAN OF COFFERDAM, LONDON BRIDGE.

together with three rows of double whole timber waleings, having the best wrought-iron screw bolts, 2 inches diameter, passing through them at every 10 feet, and well secured at their ends with wrought-iron plates and nuts, and wooden cleats as before described; there is also to be a third or outer row of whole timber piles, not less than 6 feet from the second row; the heads of this row of piles are not to extend higher than the level of half tides, that is, seven feet below high water mark of spring tides, according to the Trinity House standard, only that there are to be two piles at such distances as shown in the drawings, to the full height of the inner rows; this row of piles is to be connected together with three rows of double whole timber waleings, not less than 12½ inches square, and to be secured to the main dam with long wrought-iron screw bolts, 2 inches diameter, with plates, cleats, and nuts as before described, passing through three rows of piles at each row of waleings; at the centre of every space between the bolts belonging to the two main rows of piles, the two outer rows of piles are to be driven not less than 8 feet below the lowest part of the foundation, and the inner row not less than 10 feet, that is, the square part of the piles are to be of this depth besides the shoes; the spaces between the three rows of piles are to be properly filled with tough well-beaten clay as before described, the whole of the exterior joints being previously well caulked and covered with pitch. There are also to be proper sets of cross and diagonal half-timber braces to connect the rows of piles together, and the whole dam is to be braced longitudinally and transversely with double and single whole timber braces, struts, and wrought-iron straps and ties; at the upper, middle, and lower tiers of waleings, as shown in the drawings, there is to be a tunnel at one end of the dam, 3 feet square, secured by a sluice worked by proper machinery, as shown in the drawings, in order that the sluice may be raised and lowered when required, the above tunnel to be

well fitted and secured to the piles as before described; the whole of the piles are to be straightened and planed on the edges, and shod with good wrought-iron shoes, and properly

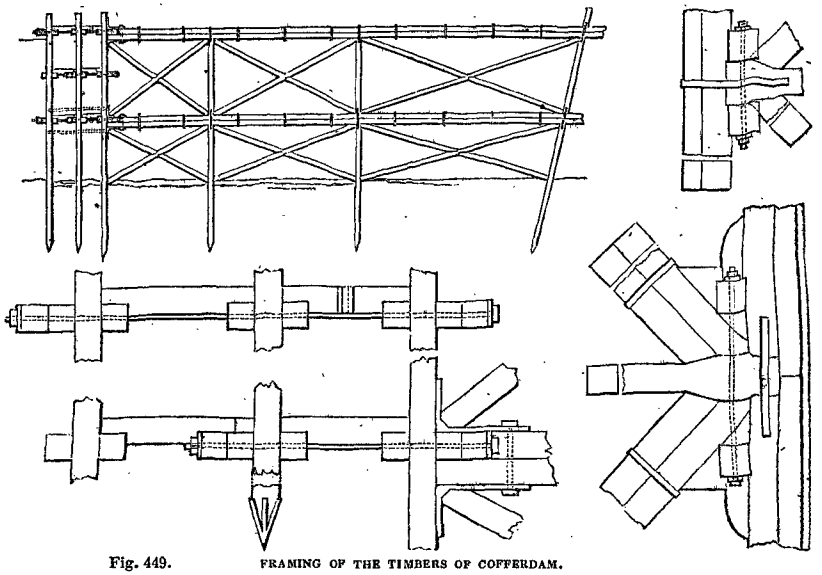


Fig. 449. FRAMING OF THE TIMBERS OF COFFERDAM.

headed and hooped with strong wrought-iron hoops of the same weight as before described, so as to prevent the piles from splitting whilst driving. There will be required four pier dams.

" *Foundations.* — The earth for the foundations of the abutments is to be excavated to such a depth, that the tops of the platforms at the front shall not be less than 34 feet 6 inches below high water mark, according to the Trinity House standard, and at the back 25 feet below the said Trinity House high water mark, and as shown in the drawings.

" The earth for the foundations of the two side piers is to be excavated to such a depth, that the tops of the platforms shall not be less than 40 feet below the said Trinity House high water mark.

" The earth for the foundations of the middle piers is to be excavated to such a depth that the tops of the platforms shall not be less than 43 feet below the said Trinity House high water mark. When the earth has been excavated to the required depth, piles are to be driven to sustain the weight of the superstructure; these are to be of elm, fir, or beech timber, not less, on an average, than 12 inches diameter in the middle, and 20 feet long, properly shod with good wrought-iron shoes, not less than 35 pounds weight each, and good wrought-iron hoops 30 pounds weight each, so as to prevent the piles from splitting whilst driving. The piles under the foundations of the abutments are to be driven at right angles to the inclination of the foundations, and those for the piers are to be driven perpendicular, as shown in the drawings; all these piles are to be driven not less than 18 feet below the under side of the respective platforms of the piers and abutments, that is, the square parts of the piles, besides the shoes are to be driven to this depth. The piles are to be driven in rows about 4 feet asunder from centre to centre, as shown in the drawings. When all the piles are driven to the requisite depth, their heads are to be cut off level and even, and the earth from between is to be excavated to the depth of 9 inches below the pile-heads, and the spaces between are to be filled with Kentish ragstone, well beat down and racked in with sharp gravel and lime screenings to the level of the pile-heads, in the proportion of one part of lime to five parts of gravel, after which sills of beech, elm, or fir timber, not less than 12 inches square each, are to be laid and fitted solidly on the pile-heads, in the transverse direction of the foundations, and firmly spiked to each pile with jagged wrought-iron spikes 18 inches long, and $1\frac{1}{2}$ inches square; between these sills, except at the extremities, which are to be filled with square blocks of stone, the spaces are to be built up with good sound brickwork, composed of the best sound, hard, well-burnt grey stock bricks, set in mortar, composed of four parts of clean sharp river sand to one part of well-burnt Merstham, Dorking, or other lime equally good; above these sills there are to be laid and properly fitted other rows of sills longitudinally over the pile-heads below,

and at right angles to the other sills: these rows of sills are to be of the same materials and dimensions as the former, and to be firmly spiked down to the lower rows of sills with

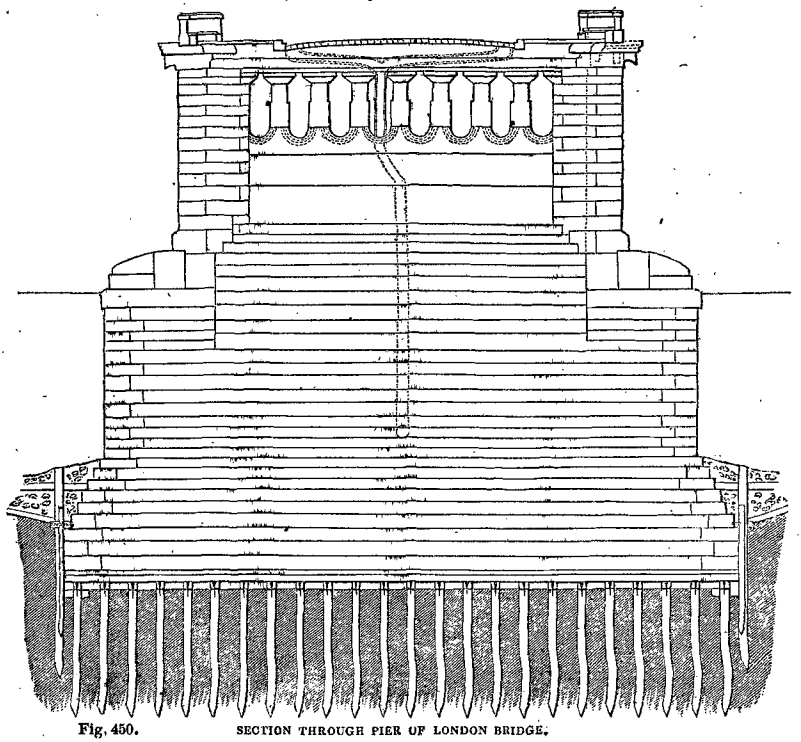


Fig. 450. SECTION THROUGH PIER OF LONDON BRIDGE.

18-inch jagged spikes, as before described. The spaces between the upper rows of sills are to be well fitted and built up level with Bramley Fall, Painshaw, or other stone equally good,

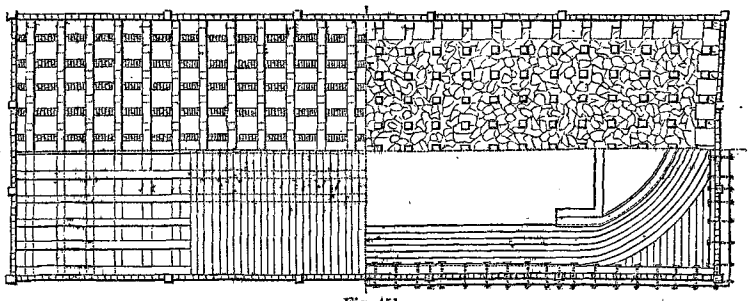


Fig. 451.

set in and grouted with mortar similar to that above described, and when made level with the top of the sills, the whole of the foundations are to be covered with 6-inch beech, elm, or fir planks, to be bedded in mortar, as before described, and to be well-fitted, close-jointed, and firmly spiked down to the sills with the best wrought-iron jagged spikes, 12 inches long, and $\frac{3}{4}$ inch square, and upon this platform the masonry hereinafter to be described is to be built. Along the front of the abutments, and on each return, and round the entire foundation of the piers, sheeting piling is to be driven to the depth of not less than 12 feet below the top of the above described platforms of the abutments, and 14 feet below the top of the platforms of the piers, that is, the square parts of the piles are to be of this depth, besides

the shoes. These piles are to be of clean beech, elm, or fir timber, not less than 6 inches thick, except those for the piers, which are to be fir timber, not less than 12 inches square, the whole to be well straightened, planed, ploughed, and tongued on the edges, and driven perfectly close, and to be connected together with half timber fir waleings, well bolted and secured to the piles. These piles are to be hooped and shod with wrought-iron hoops and shoes, averaging 26 pounds weight each for the small and 36 pounds weight each for the large piles. The above sheet piling to be pitched not less than 18 feet long each pile, and to be commenced previous to the main foundation, in order to facilitate getting down to the required depth for the foundation.

"*Stairs.*—The foundations for the stair walls in front are to be excavated to such a depth that the upper side or top of the platform may not be less than 34 feet 6 inches below the said Trinity House standard high water mark, decreasing backwards in depth according to the inclination of the abutments, as shown in the drawings; bearing piles of beech, elm, or fir timber, not less than 12 inches diameter in the middle, are then to be driven not less than 12 feet below the under side of the platform of the foundation, that is, the square parts of the piles are to be of this depth, besides the shoes, and 4 feet from centre to centre; the heads of these piles are then to be cut off and levelled, and the earth from between is to be excavated to the depth of 9 inches below, and the spaces are to be filled with Kentish ragstone as before described, well beat down, and racked in with sharp gravel. One tier of sills not less than 12 inches square is then to be laid and solidly fitted on them, and well spiked down to the piles with 18-inch best wrought-iron jagged spikes, not less than $1\frac{1}{2}$ inches square; between the sills there is to be brickwork well bedded in mortar composed of three parts of clean sharp river sand to one part of the best lime, and the whole is to be well grouted and made solid to the level of the top of the sills. The whole area of the foundations is then to be covered with a flooring of 6-inch beech, elm, or fir plank, well bedded in mortar as before described, properly jointed, and firmly spiked down to the sills with the best wrought-iron jagged spikes 12 inches long, and $\frac{3}{4}$ of an inch square; the whole of the sills and planking are to be laid so that they may break joint not less than 4 feet beyond each other.

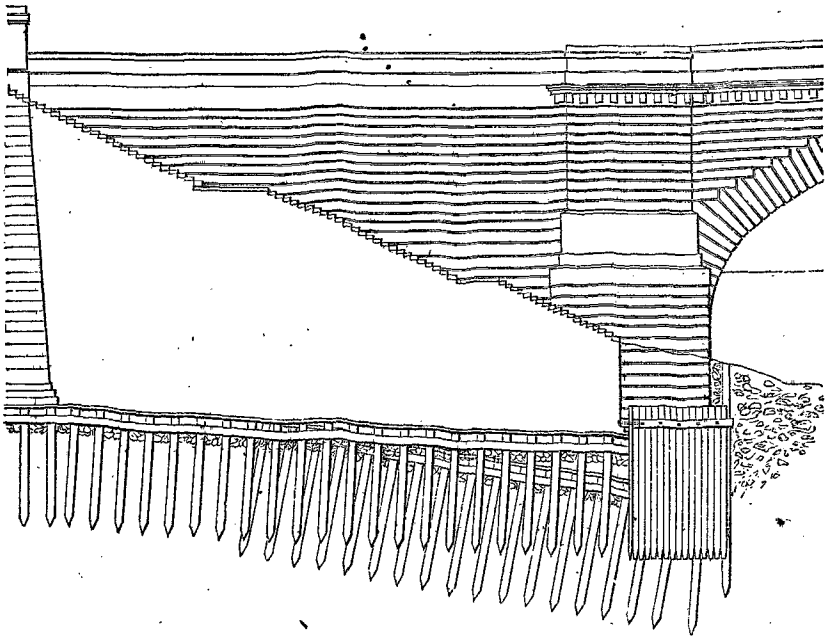


Fig. 452. SECTION THROUGH STAIRS OF LONDON BRIDGE.

"All piles that break or split in driving, or that are wrong placed, or that do not go in their proper direction, are to be taken out and replaced at the expense of the contractor.

"The masonry of the abutments up to the springing of the arches is to be built or com-

posed of ashler, in courses of not less than 15 inches nor more than 24 inches thick in the front, and the beds in the interior are to incline parallel backwards, as shown in the drawings; but the courses next to those under the springing of the arches are to be of the thickness and projection as shown in the drawings. The exterior stone, for an average depth of 5 feet 6 inches to within 3 feet below the springing of the arches, is to be composed of the best English, Scotch, Irish, Jersey, or Guernsey granite, to be approved of by the principal engineer; the interior stone is to be composed of one half of the best Bramley Fall, and the remainder of Painshaw, Derbyshire, or other stone equally good.

"The masonry is to be formed of header and stretcher courses alternately; the headers to be on an average 5½ feet long, but not less than 4½ feet long, and of the average breadth of 3 feet, but no stone to be less than 2 feet 3 inches wide.

"*The stretchers* to be on an average 5 feet long, and none less than 4 feet, and an average width of 3 feet, but none to be less than 2 feet 3 inches wide. The backing or hearting to be laid in courses of headers and stretchers alternately, the headers being opposite to the stretchers in front, and in size and thickness suitable thereto, so that the whole masonry, exterior and interior, may be completely solid and bonded together throughout every part, and double joggles to be used where and when considered necessary by the principal engineer, according to the mode shown in the drawings, and the upper bed of each course is to be dressed off smooth and even before the next course is commenced. The whole of the exterior stone is to be smooth and fine hammer-dressed on the face.

"*The horizontal beds* are to be fine dressed and rusticated 2 inches each way; but the upright or vertical joints are to be plain and perfectly straight and fine dressed for at least 15 inches inwards; the remainder of the stone to preserve its full dimension, and to be fine picked and straight between the whole of the backing or hearting, to be straight dressed in the beds and joints, and the upper bed of each course to be dressed off smooth previous to commencing the next course; all the backing belonging to each course is to preserve an equal thickness, and upon no account must it be permitted to run one course into another, except where joggles or dowels are directed to be used; the whole of the above described masonry is to be set flush in beds of the respective kinds of mortar hereinafter to be described, and properly grouted.

"*The masonry* of the piers up to the springing of the arches is to be built or composed of ashler, laid in horizontal courses of not less than 15 nor more than 24 inches thick, except the course next to those under the springing, which is to be of the thickness and projection as shown in the drawings. The whole of the exterior stone for 5 feet 6 inches inwards, except within 3 feet of the springing (which is to be of granite), is to be composed of the best granite as before described. The interior stone is to be composed of one half of Bramley Fall, and the remainder of Painshaw, Derbyshire, or other stone equally good.

"*The masonry* is to be formed with headers and stretcher-courses alternately, the headers to be on an average 5½ feet long, but none less than 4½ feet long, and on the average breadth of 3 feet, but none less than 2 feet 3 inches. The stretchers to be on an average of 5 feet in length, and none less than 4 feet long, and an average width of 3 feet, but none to be less than 2 feet 3 inches wide. The backing or hearting is to be laid in courses corresponding in thickness with the outside courses of ashler, header and stretcher alternately, the headers being opposite the stretchers in front, and in size and thickness suitable thereto, so that the whole of the masonry, exterior and interior, may be solid and bonded together throughout every part, and dowels and joggles are to be used where and when considered necessary by the principal engineer, and the upper bed of each course is to be dressed off smooth and even before the next course is commenced; the whole of the exterior stone is to be smooth, and fine hammer-dressed on the face; the horizontal beds are to be perfectly straight and fine dressed, and rusticated 2 inches each way, but the upright or vertical joints are to be perfectly straight and fine dressed for at least 15 inches inwards; the remainder of the stone to preserve its full dimensions, and to be fair picked and squared between. The whole of the backing or hearting is to be fair dressed on the beds and joints, and the upper bed of each course is to be dressed off smooth; and previous to commencing the next course, all the backing belonging to each course is to preserve an equal thickness, and upon no account must it be permitted to run one course into another, except where joggles or dowels are directed to be used; the whole of the above described masonry is to be set flush in beds of the respective kinds of mortar hereinafter to be described, and properly grouted.

"*The stair walls* to the level of the springing of the arches. These walls are to be constructed agreeably to the drawings, and to be composed of hard, well-burnt stock bricks for the interior; the exterior, to the level of the bed of the river or adjoining ground, to be composed of the best Bramley Fall stone or other stone equally good, laid in courses not less than 15 nor more than 24 inches thick, to be laid header and stretcher alternately, and on an average depth, the bed not less than 3 feet 6 inches, and above the bed of the river, to the level of the springing of the arches; the exterior to be composed of the best granite as before described, and in courses not less than 15 nor more than

21 inches thick, laid header and stretcher alternately, and an average depth on the bed of not less than 3 feet 6 inches; the upper bed of each course to be dressed smooth and even before the next course is commenced; the faces, beds, and joints of the exterior stone-work, as well as the setting, to be executed similar to that described for the abutments and piers.

"*The Centres.*—There are to be four complete sets of centres, on which the arches are to be turned; each set of centres is to consist of eight ribs properly braced together, and to be executed according to the drawings; they are to be composed of the best Dantzic, Memel, Riga, Stettin fir timber, except the springing pieces, which are to be of elm, and the

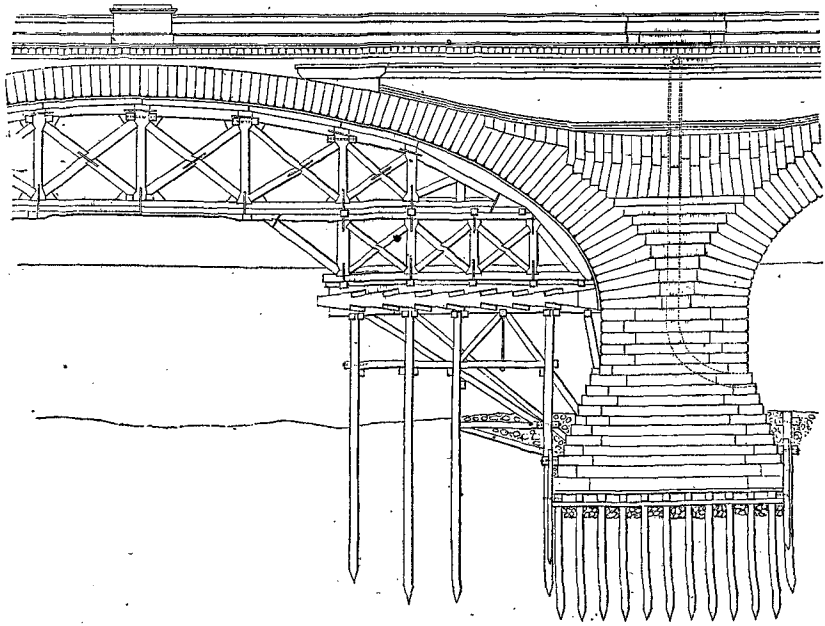


Fig. 453. PIER OF LONDON BRIDGE.

striking wedges are to be of oak of the best quality, entirely free from sap or wane, and cased on the upper and lower sides with fine sheet copper, one-tenth of an inch thick, and to be well greased previous to being put in their places.

"The iron work to be composed of the very best English iron, and to be executed as described in the drawings; the supports or trussels for carrying the centre to be of the best fir timber of the quality above described; the trussels and centres when fixed to be firm and strongly braced longitudinally and diagonally, so as to make them firm and secure.

"The covering of the centre for carrying the arch-stone is to be of good sound fir, half timber, 7 inches thick, to be carefully laid, properly levelled, and firmly packed and wedged up to the curvature of the respective arches.

"*Arches.*—The arches are to be of semi-ellipses. The centre arch to be 152 feet span in the clear, and 29 feet 6 inches rise when finished; the voussoirs, or arch-stones, to be 4 feet 9 inches deep at the crown, and not less than 10 feet at the springing. The two arches next the centre are to be 140 feet span each, and 27 feet 6 inches rise; the voussoirs at the crown to be 4 feet 7 inches deep, increasing to not less than 9 feet at the springing; the two side arches to be 130 feet span each, and 24 feet 6 inches rise; the voussoirs, or arch stones, at the crown to be 4 feet 6 inches deep, increasing to not less than 8 feet 6 inches at the springing.

"The whole of the arch-stones are to be headers, except where the engineer shall allow stretchers to be used. They are all to be 18 inches thick at the intrados or inside of the curve, and to increase in thickness to the extrados or outside of the curve, according to the radius of curvature at the respective places where they are to be used. Of these arch-stones none are to be less than 2 feet 6 inches wide, and none of them to overlap at the joints in their respective courses less than 15 inches. The length of the arch-stone is to

increase where the inverted or the abutting arches on the piers commence, agreeably to the ratio shown in the drawings, and in the abutments they are to be continued on the same line of radius to the full extremity of the abutments, diminishing from the top of the

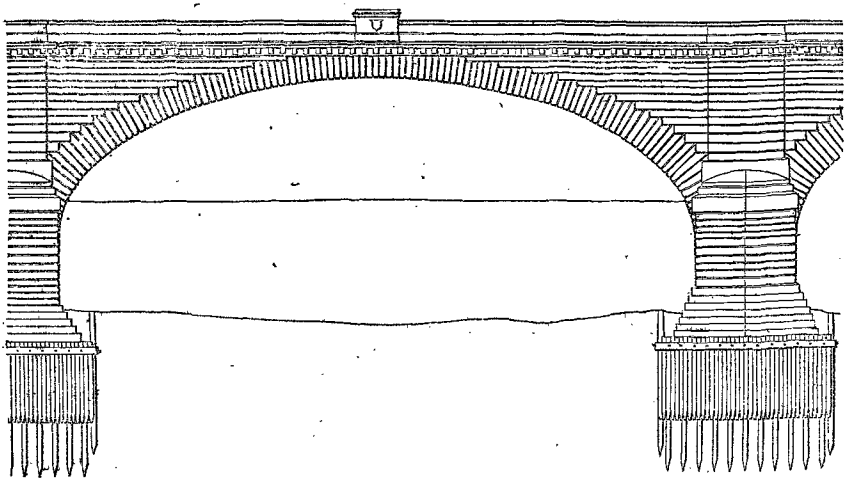


Fig 454. ELEVATION OF CENTRE ARCH, LONDON BRIDGE.

abutments until they come to the regular depth of the arches, as shown in the drawings; the outside or quoins of the arches are to continue in length to meet the horizontal courses in the spandrils between the arches.

"The arch-stones are all to be dressed perfectly smooth and straight on the beds, sides, and faces, without any deficiency whatever. The faces and soffits are to be fine-dressed and rusticated as before described; the extrados to be formed according to the drawings, and rough hammer-dressed, except where the inverted arches join, and these are to be smooth dressed, so as to bear and fit solidly in every part.

"The whole of the arches, interior and exterior, are to be composed of the best granite as before described; there are to be four sets of connecting bars, composed of the very best wrought-iron in each arch, of the forms, dimensions, and position shown in the drawings; the whole of the arch-stones are to be properly bedded and jointed in mortar hereafter to be described.

"*Solid spandrils* over the piers to the under side of the inverted arches; these are to be made up with solid masonry in horizontal courses, corresponding in thickness, and closely fitted to the extrados or back part of the arch-stones at their respective places as shown in the drawings; these are to be composed of the best granite as before described.

"The top bed of each course is to be dressed off smooth and even before the next course is commenced; the whole of the above courses of stone are to be firmly squared and dressed in their beds and joints, so that they may fit solid and close in every part, and they are to be set in beds of fine mortar hereafter to be described.

"*Inverted Arches.*—The inverted arches over the piers are to be constructed as shown in the drawings, and the depth of these inverted or abutting arches is to be 6 feet in the middle for the two centre piers, and 5 feet for the two side piers; these inverted arches are to be composed of courses not less than 18 inches thick at the soffit, and increasing in thickness according to the radius, and they are to rest on the solid spandrils before described, and to be close and accurately fitted to them and the extremities or extrados of the arch-stones; they are to be composed of the very best granite as before described; the whole of the above described inverted arch-stones are to be finely dressed in every part without any deficiencies whatever; they are to be set in fine mortar hereafter to be described: there is to be a circular opening of 18 inches diameter through the centre of each pier and through the solid spandril and inverted arches, and through the pier below the level of low-water mark, as shown in the drawings, where it is to communicate with the river to carry off the leakage or soakage water that may accumulate from above.

"*The outside spandril walls*, between the arches and against the abutments, are to be 5 feet thick, and fronted with granite, as before described, in courses of suitable thickness to those of the arch-stones, against which they are to abut, and fit closely as represented in the drawings.

" These courses are to be laid headers and stretchers alternately; the headers not to be less than 2 feet 6 inches wide in the face, and run generally through the whole thickness of the wall, but no stone to be less in the bed than 3 feet 6 inches long; the stretchers are

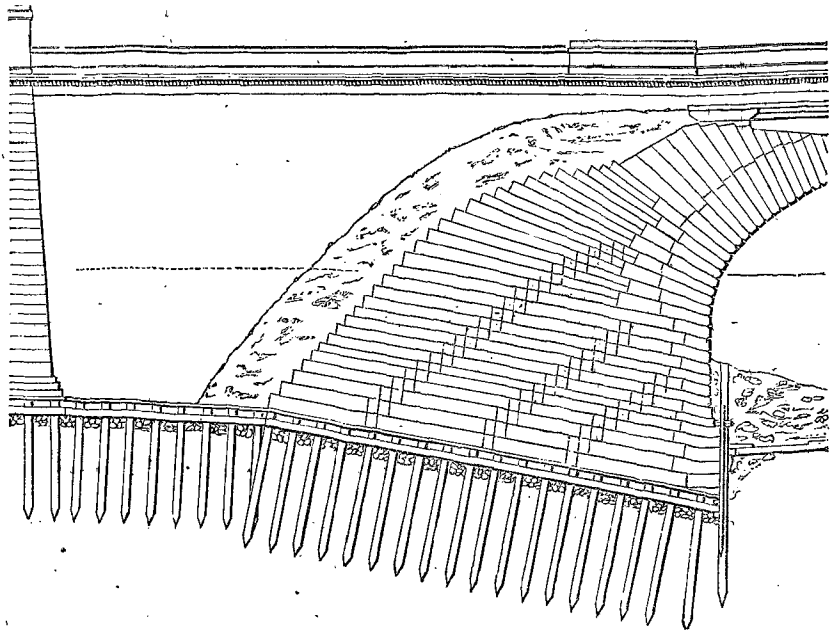


Fig. 455. SECTION THROUGH ABUTMENTS OF LONDON BRIDGE.

not to be longer than 5 feet, nor less in breadth, on an average, than 2 feet 6 inches, and no stone less than 2 feet broad: and whenever a header or stretcher is used less than the dimensions above given, the next stone is to exceed the average dimensions as much as the stone in question is under it. The backing is to be of the best Bramley Fall, Painshaw, Derbyshire, or other stone equally good, and laid in courses in thickness corresponding to those in front. The top of each course throughout to be dressed off smooth and even before the next course is commenced. The horizontal joints or beds of all the spandril courses are to be rusticated as before; the vertical joints to be plain and fair-dressed, and the outside face to be fair hammer-dressed; the interior joints to be square, close, and well-fitted. The covering or cap-stones on the point of the piers to be fair-dressed on the exterior and on the beds and joints, and they are to be secured to the facia course below with proper sized stone dowels 6 inches square, and to be of the best granite, as before described. The whole to be set in mortar hereafter to be described.

" *Buttresses.*—There is to be a rectangular buttress over each pier and abutment, as shown in the drawings, the outside to be faced with the best granite for at least 3 feet 6 inches inwards; the plinth or lower part to be plain and fair-dressed on the face; the faces and beds and joints to be properly dressed, and secured to the course below with sufficient stone dowels, and the masonry above to be in courses corresponding with those of the spandril walls, and header and stretcher courses alternately; the backing to be composed of the best Bramley Fall, Painshaw, Derbyshire, or other stone equally good, laid in courses equal in thickness with the front or outside courses, and to be straight, square, and fair punched in the joints, and dressed on the beds; the top beds of each course to be dressed off smooth before the next course is commenced, and the horizontal joints of the outside courses are to be rusticated as before, and the faces hammer-dressed in every respect as the spandril walls.

" The outside of the abutments and wing-walls above the springing of the arches is to be executed in every respect as described in the drawings, to be faced with the best granite, as before mentioned; to be upon the average not less than 3 feet 6 inches, and to be backed with Bramley Fall, Painshaw, Derbyshire, or Red Castle stone. The wing-walls to be of the thickness described, and the backing to be in courses corresponding in thickness with,

those in front. The horizontal joints to be rusticated, and to be in every respect executed in the same manner as the spandril walls and buttresses over the piers, the whole to be set in mortar hereinafter to be described.

"*Waterman's Stairs.*—The walls above the level of the springing of the arches are to be executed as described in the drawings; they are to be composed of the best hard grey stock bricks for the interior, the exterior to be composed of the best granite, as before described, and in courses of not less than 15 nor more than 21 inches thick, laid header and stretcher alternately, and average depth in the bed of not less than 3 feet 6 inches, the upper bed of each course to be dressed smooth and even before the next course is commenced, and the horizontal joints are to be rusticated as before.

"*Interior Spandril Walls.*—Previous to these spandril walls being commenced, the whole of the joints on the back of the arches and of the inverted arches are to be well cleared out, and if any opening can be found it is to be properly filled with grout, and afterwards the joints are to be well and firmly pointed with Roman cement, and the whole surface of the arches between the termination of the inner spandril walls on each side of the crown of the arches to be covered with a sufficient coating of Roman cement of the best quality; the interior spandril walls are to be composed of the best hard well-burnt grey stock bricks, laid flush in mortar of three parts clean sharp river sand to one part of well-burnt Merstham, Dorking, or other lime equally good; the interior mortar to be composed of four parts of sand to one part of lime; these are to be six in number over each pier, and to extend from arch to arch, the walls to be 2 feet 3 inches thick; on the tops of these walls are to be stone corbels 18 inches deep, projecting on each side over the walls not less than 12 inches, and there are to be corbels projecting 12 inches from the inner side of the retaining outside spandril walls; these are to be composed of Bramley Fall, Painshaw, or Derbyshire stone.

"The whole surface over these walls, and for 1 foot on each of the retaining or outside spandril walls, to be covered with good strong Yorkshire landings not less than 9 inches thick, the longitudinal joints in all cases to be over the centre of the interior spandril walls: these coverings are to be fair-dressed, and close and well-jointed, and firmly and solidly bedded on the corbels underneath, in mortar hereafter described.

"*Roadway over the Bridge.*—When the whole of the arches and spandril wall coverings have been carried up to the level for receiving the roadway, the whole surface of the bridge is to be covered with a bed of sound, tough, well-beaten clay, 15 inches thick, thoroughly puddled, and well-beaten together, so as to become perfectly impervious to water. The clay is then to be covered with 3 inches of fine sand; there is then to be a course 12 inches thick of fine flint stones, broken into small pieces, so that none are to be larger in size than 2 inches diameter; the whole is then to be well-dressed and rolled. The foot paving is to be composed of granite, as before described. These stones are to be the whole length of the footpath, that is, 7 feet 6 inches long, 8 inches thick, and 3 feet and upwards wide; on the one end they are to be properly bedded on the cornice; and at the other end they are to be supported by curbstones not less than 4 feet long, 9 inches wide, and 12 inches deep, set edgeways, to be of the best granite, as before described, and properly bedded and jointed, and set in mortar. The intermediate spaces are to be filled with fine gravel or sand, so that the paving may be bedded throughout. Along the front of these stones there are to be gutters or watercourses, paved with granite pitching paving 9 inches deep on each side, for the width of 5 feet 6 inches from the outside of the foot paving. It must be observed that the roadway is to be curved 6 inches in its transverse direction, and the clay and pavement is to incline inwards towards the gutters, as shown in the drawings.

"*Cornice and Parapets.*—The cornice and parapets are to be constructed of the best granite, as before described, and are to be executed in every respect agreeably to the drawings; they are both to be finely dressed and jointed; none of the stones belonging to the cornice, plinth, dado, or coping of the parapet to be less than 4 feet 6 inches long, and to be bonded and dowelled properly over each other, the coping to be dowelled at every joint by a projecting dowell 2 inches square, fitted into an equal recess in the adjacent stone. All the stone is to be perfectly free of blemish and deficiencies of any kind whatever.

"*Approaches.*—The approaches are to be formed of solid embankments and arches where the height will admit, as shown in the drawings; in the former case the embankments are to be supported on the sides with brick retaining walls, as shown, and where arches are adopted the piers are to be founded 6 feet below high water mark, according to the Trinity House standard, and the retaining walls 3 feet below the said high water mark; the unsound earth, for at least 6 inches below, is to be removed, and to be replaced with sound gravel and lime, in the proportion of five parts of the former to one of the latter, to be well mixed and puddled together, and to be allowed time to harden; there is then to be laid Yorkshire landings 6 inches thick, and not less than 2 feet wide, and at every 6 feet to be 4 feet wide each for the whole width of the foundations; upon the top of these landings there is to be laid a course of Bramley Fall, Derbyshire, Painshaw, Red Castle stone, 15 inches thick, 4 feet wide, and not less than 4 feet long, to be so laid as to break bond over

the landings, not less than 18 inches each stone. The piers are then to commence, and to be 4 feet wide at the bottom, and set off until at 4 feet high, they are to be reduced to 2 feet 3 inches wide. The cross walls, where necessary, are to be done in the same manner. The retaining walls above and below the springing of the arches are to be 2 feet 3 inches thick, and to batter, as shown in the drawings, at the springing of the arches; over each pier there is to be a complete course of Bramley Fall, Painshaw, or Derbyshire stone, 18 inches thick, well-dressed and bedded in mortar, hereafter to be described.

"The arches are all to be semicircular, 16 feet span each, and 18 inches deep at the crown, and increasing in the haunches, as shown in the drawings. The brickwork is to be composed of the best hard well-burnt grey stock bricks laid flush in mortar of three parts of clean sharp river sand to one of the best well-burnt Dorking, Merstham, or other lime equally good, the interior mortar to be composed of four parts of sand to one of lime.

"The roadway to be formed with 18 inches of sound tough clay, well-beaten and puddled together, so as to be impervious to water, 3 inches of sand and 12 inches of flints, broken equally into small pieces about 2 inches diameter, and mixed with a small portion of chalk at the surface, and well-dressed and rolled together; the clay, sand, and flint are to be laid inclining towards the gutters.

"On each side of the road is to be a foot pavement 9 feet wide, to be composed of the best Yorkshire landings, 4 inches thick, and laid in courses not less than 2 feet 3 inches wide, and no stone to contain less than 4 superficial feet; they are to be fair-tooled on their upper beds, and squared in their lower beds; the joints are to be properly dressed and set in mortar, before described; at their side they are to be bordered by curbstones of the best granite, as before mentioned, not less than 12 inches wide, and 9 inches thick, and 4 feet long, to break bond well with the landings, and to be properly fitted to them, the whole of the paving to be laid in the best manner. There is to be a paved gutter on each side of the road, to be done with the best granite pitching paving, as before, not less than 4 feet wide and 9 inches deep, done in the best manner.

"*Mortar.*—The mortar of the different parts of the bridge is to be composed of two kinds, namely, lime mortar and pozzolano mortar; the former is to be composed of the very best Dorking, Merstham, or other lime equally good, well-burnt and ground up in a mortar mill on the spot to a fine powder in its dry state, and afterwards mixed with the requisite proportions of clean sharp river sand and water under the mortar mill. The lime mortar for the whole exterior of the bridge and arches, with the exception hereafter to be mentioned, is to be composed of three parts of sand and one part of lime; the exterior must be understood to extend 3 feet inwards; the interior mortar to be composed of four parts of sand to one part of lime, except where otherwise mentioned. The exterior mortar for the piers and abutments, from the foundations up to the Trinity House high water mark of spring-tides, is to be composed of one part of the best pozzolano, one part Dorking or Merstham lime, and two parts of sand, to be well-mixed and ground up together under the mortar mill, as before described.

"The whole of the workmanship and materials above described to be of the best description of the respective kinds, and to be executed to the entire satisfaction of the principal engineer appointed to direct and superintend the works, who shall have full power during the progress of the work to reject all improper workmanship and materials, or to make such alterations or additions in the plans and specifications alluded to, as the nature of the foundations or the circumstances may, in his opinion, require; proper allowances being made to the contractor where additions are made, or deductions where diminished, according to the scale of prices to be delivered in and approved of at the time of making the contract; and if any difference should arise between the engineer and the contractor as to any matter, clause, or thing in the specification or plans above alluded to, the same to be decided by the principal engineer, without reference to any other party or parties whatsoever."

The contract contained the following covenants on the part of the contractors: —

"To execute and perform in a substantial, perfect, and workmanlike manner, and to the satisfaction, and according to the directions, of the principal engineer for the time being, without reference to any other person or persons, all the cofferdams, excavations, foundations, abutments, piers, centres, arches, spandrils, buttresses, stairs, walls, cornices, parapets, embankments, and other works of every description, which shall be required to be done and executed in and about the building, executing, constructing, finishing, and completing the new bridge, and the approaches thereto, and the road and footway over the same, according to the plans, and under and subject to the directions, rules, regulations, and explanations and restrictions mentioned or referred to in the above specification, with such alterations, if any, as may from time to time be directed by the principal engineer in manner hereinafter mentioned.

"To find and provide all the stone, timber, iron, bricks, mortar, lime, sand, chalk, gravel, clay, and other materials necessary for executing the works of the kinds and descriptions mentioned in the specification, to be directed by the principal engineer, or the resident

engineer acting under his directions, and of such quality as shall be approved of by the principal or resident engineer.

" To find, provide, and erect from time to time to the satisfaction, and according to the directions of the principal engineer, such steam engine, or steam engines, with proper pumps and machinery of every description, as shall be necessary to keep the works clear of water.

" To find and provide to the satisfaction, and according to the direction, of the principal engineer, or the resident engineer acting under his direction, all such places for depositing and working materials, and all such temporary roads, railways, gangways, stages, scaffoldings, pile engines, cranes, crabs, blocks, shears, tackles, chains, barrows, ropes, planks, and all such other engines, machines, tools, implements, utensils, and labour, as shall be necessary for the execution of the said works, as well at the said intended bridge as at the place or places to be provided for by the contractor for depositing and working materials; and also all such boats, barges, carriages, and labour as shall be requisite for conveying the said materials, engines, machinery, and implements to and from the places where the same respectively are to be used for clearing away superfluous earth and rubbish.

" To drive and provide such guard piles, dolphins, moorings, and other fences and protectors as shall be necessary for the safety of the works, to bear all risk and responsibility whatever attending the execution of the works, and without any delay to make good all damages of every description which may happen to the works, or any parts thereof, during the progress of the same; and pay the expenses of, or make good all settlements or defects which may happen to any wharfs or buildings near the works, and all other damages which may be occasioned by, or in consequence of, the works or any of them.

" To make and contract according to the satisfaction and according to the directions of the principal engineer, or the resident engineer acting under his directions, such works as shall be necessary for preventing the possibility of injury or damage to the present bridge or the starlings thereof, by the execution of the works, or in consequence of removing the nosings of the western extremity of the sterlings of the present bridge, which the contractor, with the approbation of the principal engineer, is authorized to take away for the more convenient erection of the cofferdams, or in consequence of any alteration in the present bridge, which shall be made with the approbation of the committee and of the principal engineer.

" In case any injury or damage shall happen to the present bridge, or the sterlings thereof, during the progress of the works, the contractor is without any delay to make good and repair the same.

" To construct, remove, and fix the cofferdams, guard piles, and moorings, and other temporary works in such places, at such times, and in such manner as the principal engineer, or the resident engineer acting under his directions, shall direct.

" The execution of the works to be arranged in such manner that a free and sufficient passage shall at all times be preserved for such vessels as can now pass through the present London Bridge.

" To provide during the progress of the works such watchmen, gate-keepers, and other persons as may be necessary for the protection thereof.

" The contractor shall constantly attend to the works during the progress thereof, and to the due execution thereof in manner aforesaid.

" All the works shall be performed, finished, and completed to the full and entire satisfaction of the principal engineer in the manner aforesaid, and according to the true intent and meaning of the contract, in or before the day of

" To clear away before the said day of , all the dams, scaffolding materials, and rubbish, and remove all other obstructions occasioned by the building of the bridge, except such part thereof (if any) as shall be directed to be left for any further time by the principal engineer.

" In case the principal engineer shall, at any time or times during the progress of the said works, think proper to cause any alterations in, or variations from, the original plans and the above specification to be made on account of the nature of the foundations, or any other circumstances, either by increasing the works, or the scale of magnitude thereof, or altering the quality of any part thereof, or omitting some part, or diminishing the works, or the scale of magnitude thereof, or altering the quality of any part of the works, or the materials to be used therein, or otherwise; and shall give notice in writing to the contractor of such alterations or variations, the contractor is to execute, perform, and complete the works according to such alterations or variations in the manner, and within the time, in which the works ought to be completed according to the true intent and meaning of the contract; and such alterations and variations shall not vacate or lessen the validity of any of the covenants or agreements contained in the contract, but such sum of money shall be added to or deducted from the sum agreed to be paid to the contractor, as the principal engineer shall estimate to be the value of such alterations or variations, according to the measurements thereof, at the prices mentioned in the scale of prices to be delivered by the contractor at

the time of making his tender, and to be approved by the principal engineer, and in case any works or materials shall be included in any alteration or variation, the price of which is not mentioned in the said scale of prices, or cannot be determined according thereto, then the value thereof shall be estimated by the principal engineer at a fair and reasonable price.

" In case any day work shall be required by every such alteration or variation as is not provided for by the said specification or the said scale of prices, the contractor is to deliver in every week to the principal engineer, or the resident engineer acting under his direction, an account of such day work as shall have been performed on account thereof; and in case any day work shall have been done of which such account shall not be delivered in within one week after the same shall have been performed, the contractor shall not be entitled to any payment or compensation in respect thereof.

" If any materials provided to be used in or about the works shall not be approved of by the principal engineer, or the resident engineer acting under his direction, previous to their being brought into use, he shall be at liberty to reject the same, and if the contractor, his executors or administrators, shall not, within twenty-four hours next after notice of such rejection shall have been given or left at his usual or last place of residence, or with his foreman or clerk of the works, clear away and remove the same, it shall be lawful for the principal engineer, or the resident engineer acting under his direction, to order the same to be carted to the city greenyard, and forthwith to sell the same, and out of the money arising from such sale to pay all expenses occasioned by such removal and sale, and to pay the surplus only (if any) to the contractor.

" In case the principal engineer, or the resident engineer acting under his direction, shall disapprove of the workmanship or execution of any parts or part of the works, the same shall be immediately taken down and re-executed, or altered to his satisfaction, and in case the contractor shall not within three days after notice in writing of such disapprobation shall have been given to him, or left at his usual or last place of abode, or with his foreman or clerk of the works, proceed to take down, alter, amend, or rectify such disapproved part of the works, then it shall be lawful for the principal engineer, or the resident engineer acting under his direction, to employ other workmen to take down and amend and rectify the same, and that the contractor shall permit the mayor and commonalty and citizens of the city of London, or the committee, to retain out of the money which may be due to the contractor on account of the works, the amount of the bills of such other workmen, for and in respect of their work, labour, and materials which may have been done, performed, and used in and about the rectifying or amending such part of the works; and in case the monies due on account of the works shall not be sufficient to satisfy the bills of the said other workmen, then the contractor shall, on demand, pay unto the said mayor and commonalty and citizens, or their successors, or to the said committee, so much of the amount of the bills as the said monies shall be insufficient to satisfy.

" In case the contractor shall refuse or neglect to perform the works, or any of them, in manner hereinbefore described, or in the specification mentioned, or to obey and comply with any orders or directions to be given by the principal engineer, or the resident engineer acting under his directions, or in case at any time during the progress of the said works there shall appear to the principal engineer to be any unnecessary delay in the carrying on of the works, or any part thereof, either by not employing sufficient number of workmen, or otherwise howsoever, or in case any of the works shall not be performed to the satisfaction of the said principal engineer, or shall not be finished within the time hereinbefore mentioned for completing the same, or in case the said contractor shall depart this life before the said works shall be fully completed, then, and in any such case, it shall be lawful for the said committee, if they shall think proper, any time before the said works shall be completed, by any writing signed by their clerk, to be given to the contractor, his executors and administrators, or left at his or their usual place of residence, to revoke and make the contract void, and every clause, matter, or thing therein contained, so far as relates to the subsequent part of the works, and the same shall be thereon null and void; and in case such declaration as last aforesaid shall be made during the progress of the works, that only part of the money to be paid to the contractor shall be paid in respect of such part of the works which shall have been executed, as shall be estimated by the principal engineer to be the value of such part according to the scale of prices before mentioned, and in consequence of any omission in the scale of prices, any part of the works cannot be estimated thereby, the value of such part thereof shall be determined according to the judgment of the principal engineer.

" In case the said committee, in pursuance of the powers before given them, shall make the contract void, the contractor, his executors or administrators, shall not remove or be entitled to remove or take away any of the dams or engines made or erected and placed in or upon or near to the works for the purposes thereof, or any of the materials found or provided for carrying on the same, until the principal engineer, or the resident engineer acting under his direction, shall permit the same to be removed, but the value of such materials, and of the

use and employment and wear and tear, or the purchase (as such engineer may think most expedient) of such engines, dams, and works as the said principal engineer shall think proper to be retained shall be estimated and determined by the principal engineer, and shall be paid or allowed to the contractor, his executors or administrators, together with such sum of money as he or they shall be entitled to in respect of the part of the works which shall have been executed.

"The direction, certificate, valuation, and opinion of the principal engineer respecting the execution of the works, the quality of the materials employed, the value of the works executed, any alterations or variations from the plans and specification hereinbefore mentioned or referred to, or of any part of the works which shall have been executed, or of any engines, dams, machinery, or materials, or the construction of any matter, clause, and thing contained in the contract, specification, or scale of prices, or either of them, or otherwise, respecting the premises, shall be final and conclusive on the contractor without reference to any other party or parties whomsoever."

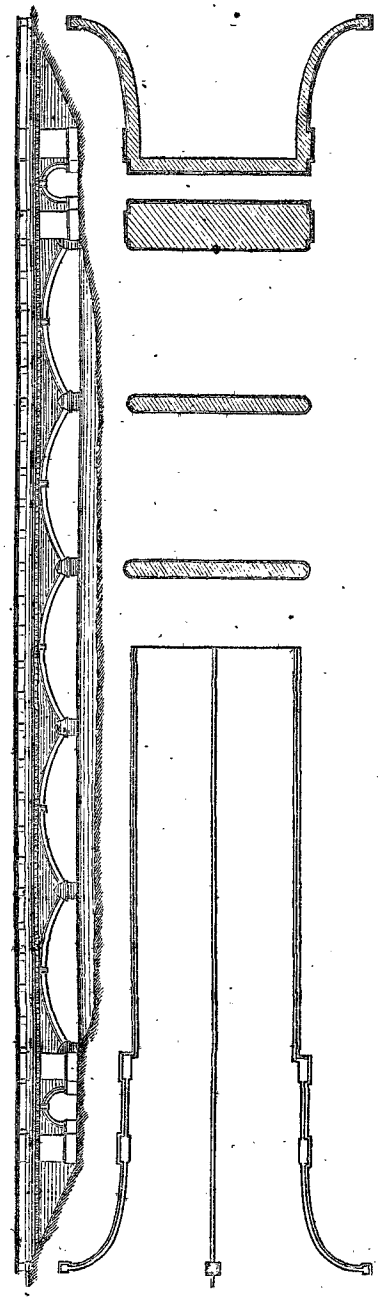
This splendid bridge, which has not its equal in the world, reflects the highest credit on all concerned in its erection, and, as long as it majestically spans the Thames, will be considered a masterpiece of construction. It was opened to the public on the 1st of August, 1831, with great pomp, after having been in progress seven years and three months.

The general depth at which the foundation of the piers is laid below low water is about 29 feet 6 inches, and the total quantity of stone used in constructing the bridge and its abutments was 120,000 tons; the number of piles of 20 feet in length under the piers and their abutments was 2092, and the total number for the cofferdams 7708. There were four sets of timber centres, each weighing on an average 800 tons.

The amount of Messrs. Joliffe and Bank's estimate for the bridge alone, including an extra set of centres, was only 425,081*l.* 9*s.* 2*d.*, the remainder of the sum previously mentioned being swallowed up in the purchase of land, houses, compensations, and law expenses.

Staines Bridge is a very beautiful structure of five segmental arches of equal span, with a smaller through the abutments, which serve for the use of the towing-horses; it was completed in the year 1832, under the directions of Mr. George and Sir John Rennie, sons of the eminent engineer to whose works we have already alluded.

The span of each arch is 74 feet, and the versed sine 9 feet 3 inches; the diameter of the circle of curvature at the vertex is 156 feet, and the height of the key-stone is 3 feet.



ELEVATION OF STAINES BRIDGE.

Fig. 456.

The cofferdams, though much smaller, were constructed in a similar manner to those of London Bridge; a double row of piles, diagonally braced and firmly bolted together, confined the clay and puddle, which kept out the water during the progress of the works.

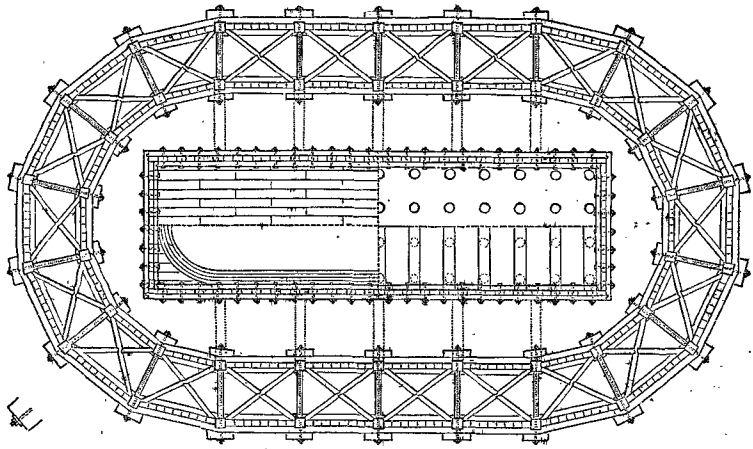


Fig. 457. STAINES BRIDGE; COFFERDAMS.

Under the piers piles were driven, as shown in the plan, which were crossed with strong timbers, and planked over for the footings of the piers; a row of sheet piling was driven

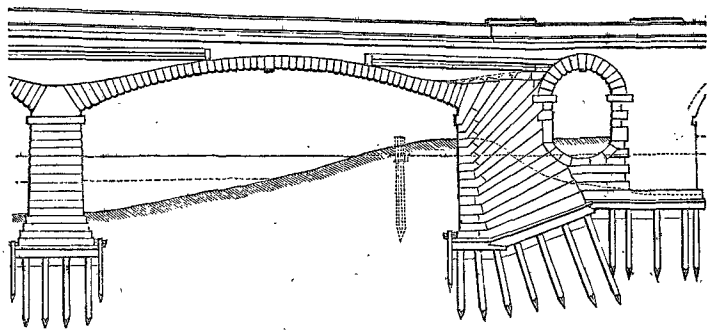


Fig. 458. STAINES BRIDGE; ARCH AND ABUTMENT.

all around at the toe or outside of the planking, to maintain the solidity of this portion of the structure.

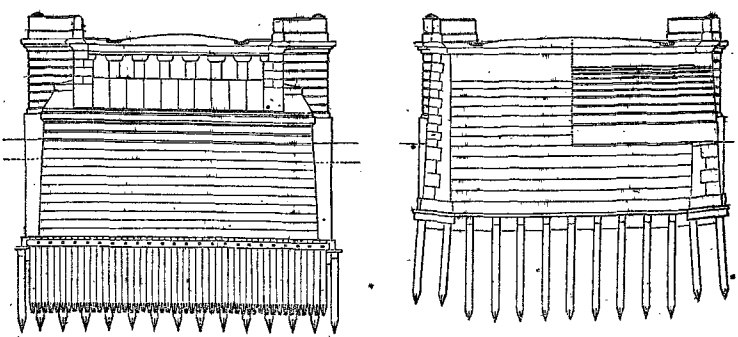


Fig. 459. SECTION OF ARCHES.

The arches are light and elegant, and remarkable for their boldness and little rise; the voussoirs are admirably proportioned, increasing in depth towards the abutments, where

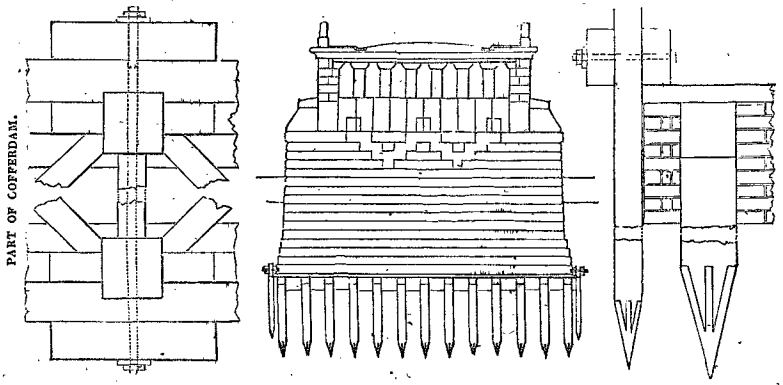


Fig. 460. [SECTION OF PIER.]

greater strength becomes necessary; the abutments are admirably constructed, the several courses which receive the thrust or pressure of the arches being made to radiate to the centre of the circle, from whence the segment of the arch is struck.

The section through the arch exhibits the foundations, sheet piling, and manner that the crown supports the roadway, which has a footway on each side, and paved channel to collect the water which falls upon the bridge, and which is conducted into pipes and carried off below. The piles are shod with iron, and driven till they come into a hard bed of gravel, and the cofferdams were securely tied together with iron bars, which could be screwed tighter, when necessary, by means of the nuts at their ends.

Hyde Park Bridge, erected from the designs and under the superintendence of Mr. George Rennie, is a beautiful structure of three arches, each 40 feet span, with a versed sine of

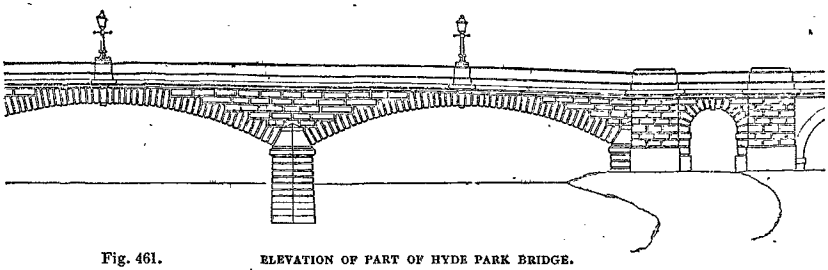


Fig. 461. ELEVATION OF PART OF HYDE PARK BRIDGE.

4 feet 10 inches; the radius from which the arches are struck was 45 feet, and the round of the segment is 42 feet. It was commenced in 1824. The construction does not materially differ from the bridge last described.

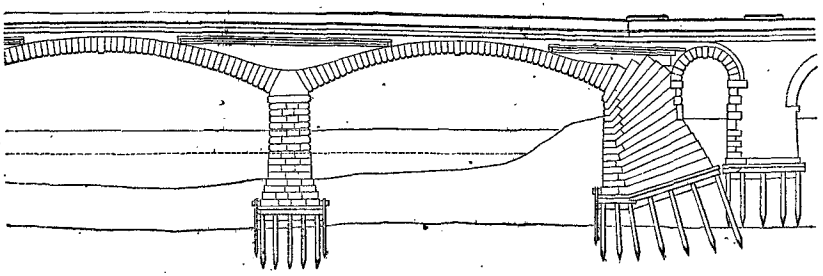


Fig 462. SECTION.

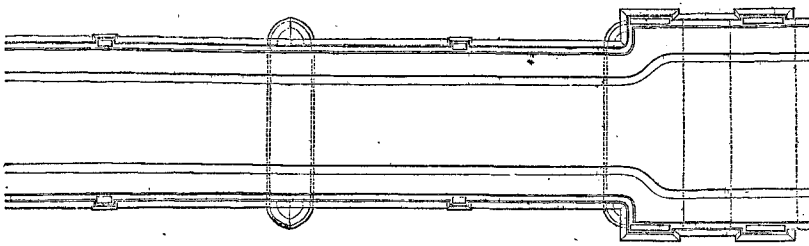


Fig. 463. PLAN.

It must be admitted, after the description given of the bridges erected in England at the commencement of the present century, that our engineers have exhibited great science, and introduced such a method of construction as has greatly economised material. The thrust and pressure of the arch on its several points are better understood, and the nature of the materials employed is also more thoroughly known: the qualities of all used in such constructions have been tested by Mr. George Rennie upon a large scale, and their capacities of expansion and contraction under the various changes of temperature examined and reported upon most satisfactorily by that eminent engineer. He has also subjected the metals, stone, timber, and brick, to severe pressure, and ascertained their relative strengths and fitness for construction.

Chester Bridge, for which an act was obtained in 1825, is one of the last designs of Mr. Harrison, an architect of that city; it has one segmental arch of stone over the Dee 200 feet span, the largest yet constructed; the key-stone is 54 feet above the level of low water mark, and the roadway is 33 feet in width.

This bridge is situated between the castle and the village of Overlegh, immediately at the head of the harbour, where the tide rises 12 feet at ordinary springs. The abutments are founded on the solid rock, except for a small portion, where it was necessary to pile. The arch is the segment of a circle whose radius is 140 feet, and the rise, or versed sine, 42 feet. The voussoirs at the crown are 4 feet deep, and increase towards the springing, where they are 6 feet. The centre, executed by Mr. Trubshaw, the contractor, consisted of six ribs in width; the span of the arch was divided into four spaces by three piers, at regular distances, built up in the river, from which the timbers spread like a fan towards the soffite, so that each timber received its weight in the direction of its length; the lower ends of these radiating supports rested on cast-iron shoes, placed on the tops of the stone piers, and the upper ends were bound together by two thicknesses of 4-inch plank, cut and arranged to follow the form of the arch; on these were laid the *lagging* or covering, 4½ inches thick, which was supported over each rib by a pair of folding wedges 16 inches long, and 1 foot broad, tapering about 1½ inches; each course of voussoirs had six pair of striking wedges. The horizontal timbers of the centre were 13 inches deep, and the six ribs were tied together transversely near the top by bolts of inch iron; the timber used was fir, and the quantity required about 10,000 cube feet. When the centre was removed the crown sunk only 2½ inches. The cost of the bridge was 42,400*l.*, and the approaches 7500*l.*, making a total of 49,900*l.*

One of the chief bridge-builders at the end of the last and commencement of the present century was Thomas Telford, who rendered his name celebrated throughout Europe by the erection of the Menai suspension bridge; he was born at Westkirk, in the district of Eskdale, the 9th of August, 1757, and died the 2d of September, 1834, aged 77. Few men have done more to advance the profession of the civil engineer: he commenced life as a mason, on the property of the Duke of Buccleuch, and afterwards worked at Somerset House, under Sir William Chambers, about 1787; his talent and industry gained him the good opinion of Sir William Pultenay, for whom he had done some repairs at Shrewsbury Castle, and by him he was appointed surveyor to the county of Salop. His first public work was a bridge over the Severn, at Montford, four miles west of Shrewsbury; it consists of three elliptical arches, one of 58 feet, the others 55 feet span, and measuring 20 feet across the soffite; here he made use of cofferdams for the construction of the piers, and the whole was satisfactorily performed with the red sandstone of the country for 5,800*l.*

Buildwas Bridge, mentioned among those constructed of iron, was his next work, after which he built upwards of forty stone bridges in the county of Shropshire, the span of the arches varying: two were 85 feet span; three of iron, 55 feet; one of stone, 50 feet; four of stone, 40 feet; two of stone, 35 feet; one of iron, 27 feet; two of stone, 24 feet; nine of stone, 20 feet; and sixteen less than 24 feet span. For the last twenty-eight years of his life he was engineer under the commissioners for making the Highland roads, bridges, &c.

Gloucester Stone Bridge, built by Mr. Telford, has but one arch, of 150 feet span and 35 feet rise. The idea of this bridge is taken from that over the Seine at Neuilly built by Perronet. The voussoirs or external arch-stones have the same chord as the inner arch, but its segment only rises 13 feet. By this means the arch has the form of a funnel, which suits the contracted passage of the waters, and lessens the flat surface opposed to the current when the waters rise above the springing of the ellipse, that being at 4 feet above the level of low water.

This work was commenced in July, 1826, upon a soil, the stratification of which was found by boring through to be from the surface of the ground, 11 feet of loam, 12 feet of blue silt, 5 feet of peat moss, 5 feet of brown clay, 3 feet of strong coarse indurated gravel, and 8 feet of finer gravel or coarse sand, in all 44 feet.

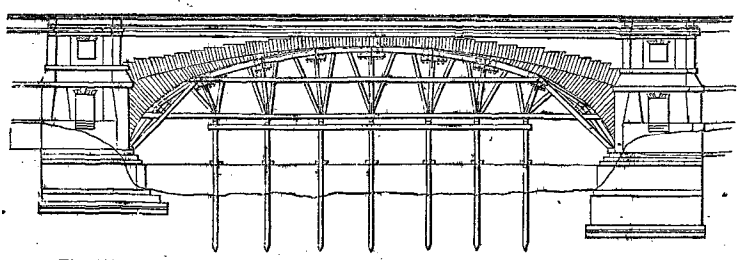


Fig. 464. GLOUCESTER BRIDGE.

The foundations were laid upon the indurated gravel, at about 15 feet below the bed of the river. A space of 40 feet square was excavated to the depth of 33 feet below the surface of the meadow, and a very strong cofferdam was made to protect it, as the floods occasionally rise 6 feet or more above the banks of the river. The cofferdam was formed of piles of Memel timber, 32 feet in length, with a space of 5 feet between the outer and inner circumference of piles; this space was filled with clay worked into water-tight puddle.

After the gravel was made level, a course of large and flat bedded rubble stone was laid over the whole space, and upon this was carefully bedded the timber platform. This consisted of thirteen pieces of Memel timber made straight and level; those laid at right angles with the stream were 37 feet in length, and those placed up and down the stream, 40 feet in length. These pieces of timber were crossed, and laid at equal distances, the square spaces between them being filled with rubble masonry well grouted. Upon these pieces of timber, or sleepers, was a covering of 4-inch beech plank, planed, closely jointed, and spiked down, thus forming a level platform, 40 feet by 37 feet, and upon this the masonry was laid.

The stone employed for backing above low water mark was brought from the quarries at Highley and Alveley, 6 miles from Bewdley; its thickness varies from 14 to 24 inches, and its weight from one to three tons. They were squared on all sides, and well bedded; every course was brought to a level and grouted before any of the next were set. All the external masonry was from the quarries of Colford and Quitchurch in the Forest of Dean.

The abutment on the west side of the river was of the same dimensions, the only difference being, that the gravel was found at 27 feet below the surface of the meadow. No piling or platform was used to the wing-walls, and they are in consequence defective on the eastern side.

The centre was supported by six parallel rows of piles, fixed in the current of the river, each row being connected by cross braces and caps; each supported a rib which formed the actual centering. The whole was steadied by diagonal braces; and between the caps of the piles, and the ribs which rested on them, the wedges were placed by which the centering was slacked or lowered after the masonry was keyed.

The depth of the arch-stones at the springing is 5 feet 6 inches, and at the key 4 feet 6 inches; this sunk 10 inches after striking the centre. The thickness of the abutments at the springing of the ellipse is 27 feet 2 inches, besides the wing-walls, which are 7 feet each, the spandrill walls are 3 feet 6 inches thick, exclusive of the pilasters.

The four longitudinal walls of the interior, which support the platform of the roadway, are each 2 feet thick; the width of the carriage-way is 27 feet, with a footpath of 4 feet on each side.

Centering.—A platform was prepared, perfectly level, rather larger than the intended centre, on which it was struck out the full size, the centres of the different radii being fixed. Dantzic timber was employed in scantling 15 inches square.

The piles were of Memel, with wrought-iron shoes, and caps at the top to the proper

height. On these were laid another tier of beams, lengthways to the centre, one under each rib; upon these beams the wedges were fixed, which were of three thicknesses, the bottom one being bolted down to the beams; the tongue or driving piece in the middle was of oak, well hooped at the driving end; the top side of the upper piece was laid perfectly level and straight, both transverse and longitudinally. The wedges were rubbed with soft soap and black lead before they were laid upon each other.

Each rib of the centre was then brought and put together upon a scaffold made upon the top of the wedge pieces, and lifted up whole, by means of two barges on the river and two cranes on shore. The scaffold was extended 30 feet beyond the striking end of the wedges, to lay the last ribs upon, previously to raising, and for the workmen to stand upon for finally striking. After the ribs were properly braced, they were covered with the 4-inch sheeting piles which had been used in the cofferdams.

This centre was so well formed, that when the arch was keyed, its sinking was not more than an inch, and it was struck in the short space of three hours. This was performed by placing beams upon the top of the work directly over the ends of the wedges; to these beams was fixed a tackle, and at its lower end was slung a heavy ram of 12 cwt., with which the piles were driven; this ram was swung to and fro, so as to strike the driving end of the tongue-piece of the wedge. This operation required eight men to pull it back, and two men to bring it forward; after twenty or thirty blows the wedges started, they then slid easily, and pieces were put in to stop their going further than was required. The covering was then taken off, and the ribs were let down, in the same order in which they were put up; and when taken to pieces were carried on shore. The bearing piles were then drawn by two 42 feet levers and strong chains.

Bewdley Bridge, over the Severn, in Worcestershire, being injured by the great flood of 1795, an act of parliament was obtained to raise money, and levy a toll, that a new bridge might be constructed; and Mr. Telford furnished the design for one of stone, of three

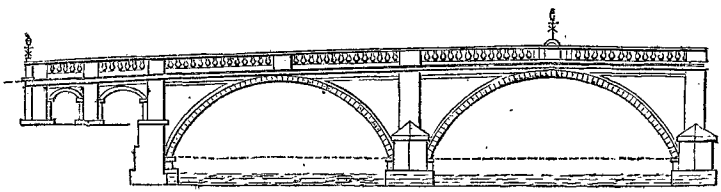


Fig. 465. BEWDLEY BRIDGE.

arches, the centre having a span of 60 feet, and the two outer 52 feet each; the breadth, measured across the soffite, is 28 feet. The versed sine of the centre arch is 18 feet, and that of the two others, 16 feet 9 inches each. This bridge was completed in 1798, at an expense of 9264*l.*

Bridge at Tongueland, near Kircudbright in Scotland, over the river Dee, has but one arch with a span of 112 feet; the width measured across the soffite is 24 feet. The depth of water at ordinary spring tides is 30 feet, and it required considerable skill to support the centre to an arch of such magnitude. In order that the arch should not be unnecessarily

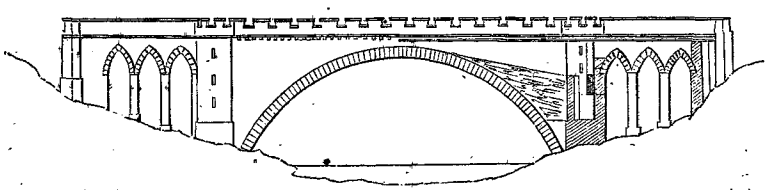


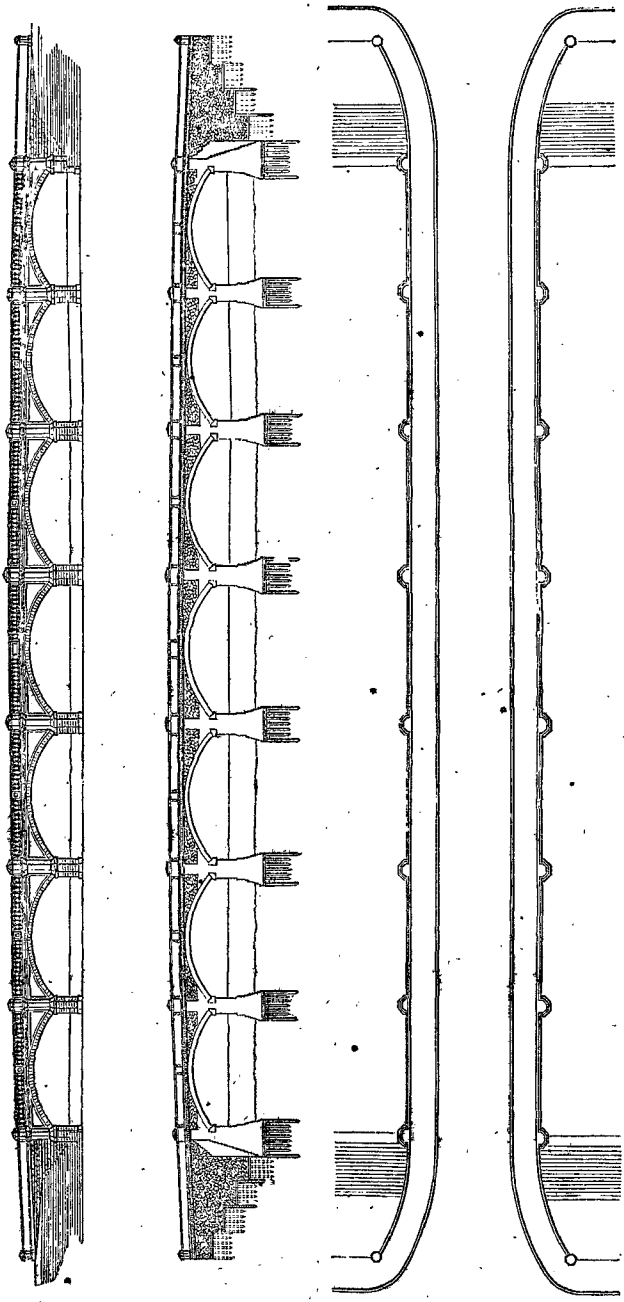
Fig. 466. TONGUELAND BRIDGE.

loaded, a number of longitudinal walls were carried up to the level of the road, where they were covered with flat stones, by which means the state of the arch may be at any time examined; this system is a considerable improvement upon the usual practice of filling in the spandrills with loose earth, which frequently produced an external pressure and destroyed the work.

The foundations of this bridge were laid in March, 1805, and completed in November, 1806, at the cost of 7710*l.*

Glasgow Bridge, built by Mr. Telford, consists of seven segmental arches, diminishing in their span towards the abutments; that in the centre has an opening of 58 feet 6 inches, and a versed sine of 10 feet 9 inches; the two adjoining are 57 feet 9 inches, with versed

sines of 10 feet 5 inches; the next two 55 feet 6 inches, with versed sines of 9 feet 8 inches; and the two adjoining the abutments are each 52 feet, with versed sines of 8 feet 3 inches.



GLASGOW BRIDGE.

Fig. 467

The piers of the centre arch are 9 feet in thickness, the next 8 feet 6 inches, and the other 8 feet; the water-way in the clear is 389 feet, the thickness of the piers 51 feet, and the clear width between the abutments 440 feet.

The clear width between the parapets of the bridge is 58 feet, and measured on the soffite of the arches 60 feet.

The subjoined specification shows the manner in which the works were executed, and requires nothing further to convey a clear notion of its construction.

"*Cofferdams.*—Before any works can be proceeded with, it is necessary that all the stones that lie upon the bed of the river, where the cofferdams are to be constructed, should be cleared away; and afterwards the foundation deepened as far as practicable with safety, so as not to alter the level of the water above bridge by too much lowering the bed.

"The cofferdams are to be formed by driving two rows of gauged piles at a parallel distance of 5 or 6 feet apart; the area comprised within the inner row being not only sufficient to allow the foundations of the pier to be laid, but also a width of a 3 or 4 feet clear space entirely around it, for the convenience of the masons and other workmen employed.

"The timber employed may be either Dantzic, Memel, or red American pine, care being taken to select that which is perfectly sound; these gauge piles, when about 30 feet in length, are to be made of whole timber, about 12 inches square, pointed and shod with iron, each shoe weighing about 12 pounds; the heads also to be hooped with the best scrap iron, not less than 3 inches in breadth, and $\frac{5}{8}$ inch in thickness, to prevent their splitting when under the weight of the pile-driving machine. A bench mark is established, to the level of which all the piles are to be driven, and which serves as a guide to the workmen.

"That each row of gauge piles are to be closely wedged together, and driven 6 feet apart from centre to centre; care being taken that they are quite perpendicular, and truly range with each other. Double waling pieces, 12 by 9 inches, are to be laid horizontally on each side, and secured to the heads of the gauge piles by $\frac{3}{4}$-inch iron screw bolts; and at 8 or 9 feet below them to be attached another horizontal row, forming a double groove to receive the sheeting piles, which are to be wedged in closely between the gauge piles.

"The dam sheeting piles, 12 by 6 inches, are also to be shod with wrought-iron shoes, of about 9 pounds weight, and to be hooped with the best scrap iron, $2\frac{1}{2}$ inches broad, and $\frac{5}{8}$ inch thick. These sheeting piles are to be driven down to the level of the gauge piles, and in a manner that the last firmly wedges all the rest in the bay, and makes them join closely together.

"The engines employed to drive the gauge piles are to carry a ram of not less than 12 cwt., and for the dam sheeting pile 2 cwt. less; and it is necessary to construct scaffolding and proper stages for the performance of these works in the most convenient situations.

"After the dam is completed, the soil is then to be taken out between the two rows of piles to the depth determined by the engineer, and a sluice trough introduced, for the purpose of letting water into the dam, when it rises on the outside to a height which would endanger its stability; in rivers subject to floods this is of the highest importance, otherwise the dam might at such times be liable to be blown.

"After the soil has been removed between the two rows of piles, the gauge piles of the respective rows are then to be connected by round iron screw bolts, made to pass through them, as well as through the centres of the two rows of waling pieces. Each of these screw bolts is $1\frac{1}{4}$ inch diameter, and is provided with a wrought-iron washer $\frac{3}{8}$ inch thick, and 4 inches square, placed under the head of the nutt, to prevent the wood of the waling yielding to the strain.

"When this is performed, pounded clay well puddled is to be introduced between the two rows of piling, and the whole worked together, until the dam has become perfectly water-tight; then the pumping out of the water to be commenced by means of a steam-engine.

"In pumping out the water, and excavating the soil from the interior of the dam, it is necessary to guard against and prevent the sand from blowing up through the bottom: this may sometimes be done by driving the foundation piles, which consolidates the sand and allows of its being taken out to the required depth; at other times it may be requisite to drive extra piles all around, before it would be safe to take out all the earth to the required depth.

"As the works of excavation proceed, the dam will require bracing, otherwise the outward pressure would force it inwards, which is to be done according to the directions given by the engineer.

"*Piling for the foundations.*—The outside rows of foundation piles are to be either Memel, Dantzic, or sound American red pine; and the gauge piles 12 by 12 or more, as the length exceeds 30 feet, to be driven 6 feet from centre to centre. Waling pieces are to be bolted to them as before directed, for keeping the intermediate sheet piling between them in a regular line. After these sheet pilings have been driven to the required

depth opposite to each joint, others of the same thickness and half the breadth are to be driven, and then the whole firmly united by walings and iron bolts.

"The piles driven inside, and which support the foundations, are to be made of beech or newly-cut Scotch fir cleared of its bark, shod and hooped as before described; after they are driven to a bench mark, all the heads to be cut off to an exact level, to receive the sleepers and the timber platform; but before this is established, the soil is to be taken

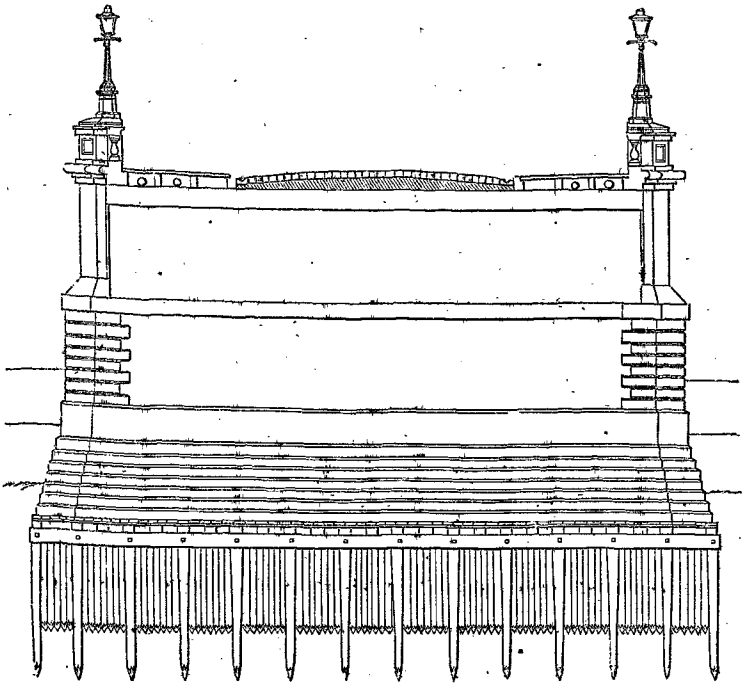


Fig. 468. GLASGOW BRIDGE.

out between the heads of the piles to the depth of 1 foot or more, and the space filled in with hand-set rubble, well packed, and laid flush in good water-lime mortar.

"*Foundation sleepers.* — Upon each transverse row of piles is to be laid a sleeper, extending across the whole width of the pier or abutment, secured to the head of each pile by a wrought-iron ragged bolt of ¾-inch round iron, 15 inches in length or more, according to the depth of the sleepers, and between each row of sleepers filled in with hand-set rubble, laid in good water-lime mortar,

"*Platforms.* — Upon the sleepers are to be laid two floors of Dantzic, Memel, or American red pine planking, to cross each other at right angles, spiked down with long spikes, and firmly united to the sleepers.

"*Masonry.* — After the foundation platforms are completed, then the mason to commence with his work.

"*Dressing of ashlar.* — The whole of the stones which compose the piers and abutments must be truly squared throughout, and should have chisel drafts round the faces, beds, backs, and end joints, and be truly pick-dressed down the drafts. The outside face work, from the bottom of the foundation to the level of low water line, should be broached in horizontal lines, not coarser than eighteen to a foot.

"*Granite facings* should be of uniform colour and quality, and laid in alternate courses of headers and stretchers; the headers, where they have 2 feet in length of face, are to have as much on the bed; the stretchers should be 6 inches longer, and not less than a foot in width on the bed. Each stone should be truly squared, and fair dressed on the beds and joints, full throughout, the backs scapelled, and the fronts rough picked; the front arris being axed or chisel drafted, so as to make a close joint on the face.

"*Ashlar hearting.* — The hearting masonry to the piers or abutments to be squared ashlar, well dressed, and laid in courses of uniform thickness throughout, and agreeing with that of

the facing; no stone should contain less in its bed than 4 superficial feet, and should be of a size to break joint at least a foot with the stones adjoining.

"*Freestone* masonry of piers and abutments should be laid in alternate courses of headers and stretchers; the headers not to present an outside face of less than 2 feet, and all to extend at least 3 feet in length into the body of the work; the stretchers not less than 3 feet in length, and in breadth 2 feet on the bed.

"No stone used in the interior of the work to have less than 4 superficial feet on its bed,

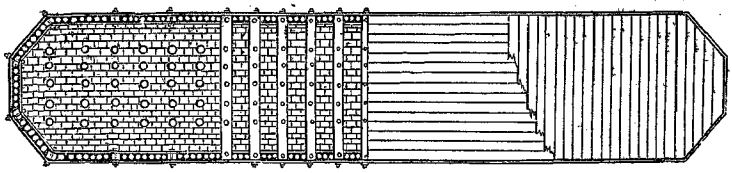


Fig. 469. GLASGOW BRIDGE; PLAN OF PIER.

and to be of the same thickness as the courses on the outside. The whole to be square dressed throughout, to be laid on its natural bed, flushed in with good lime mortar used fresh, and of a quality that will harden under water.

"*Arch-stones* or *voussoirs* must be of the dimensions designed, and should break joint with the adjoining stones at least 1 foot; their beds should be truly radiated, chisel drafted round the edges, and neatly picked dressed within the drafts. The soffite faces neatly

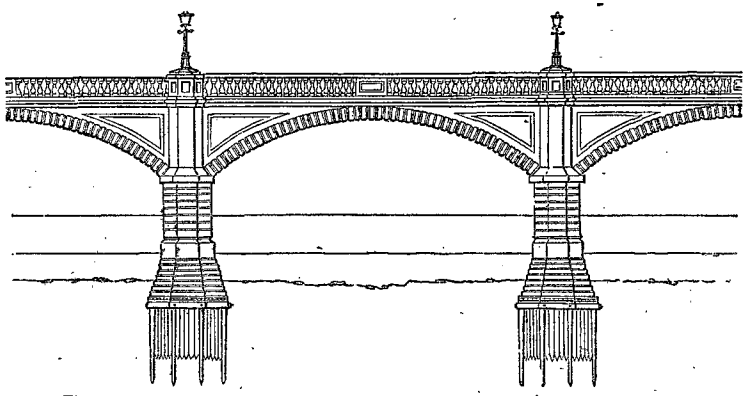


Fig. 470. GLASGOW BRIDGE.

broached in horizontal lines parallel to the beds, all carefully bedded, by bringing each stone down to its place with a wooden maul.

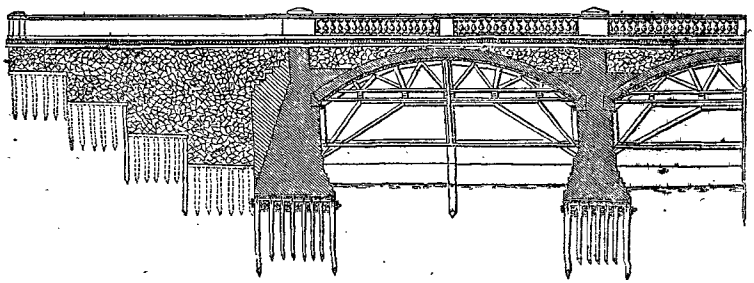


Fig. 471. SECTION OF ARCH OF GLASGOW BRIDGE.

"*Spandrill facing*, if of granite masonry, to have its stretchers 12 inches on the bed, and one fourth of each course made headers, passing at least 1 foot 9 inches into the solid wall, no course being less than 14 inches in height, the courses beneath generally being made

more; each stone should be at least 30 inches in length, and break joint 1 foot with those adjoining.

"*Rubble backing* of spandrills to consist of hammer-dressed rubble masonry, laid in regular courses on their natural bed, not more than two stones in thickness for one of outside ashlar; all properly bonded with the facing stones, as well as among the others they are laid with.

"*Interior spandrills* to be of good rubble masonry, hammer-dressed, and laid flush in good water-lime mortar.

"*Spandrill hearting* to be built up solid between the backs of the arch-stones to the level of the water, and composed of good hammer-dressed rubble masonry, laid in regular courses on horizontal beds, well flushed in water-lime mortar.

"*Cross walls* over each pier and abutment may be either of rubble masonry or brick.

"*Gutters and curb-stones.*—The gutter stone of granite, 14 inches wide, and 9 inches deep, to have cut in it a triangular water channel, 8 inches wide and 4 inches deep; the curb, 15 inches deep, and 12 wide, formed also of granite, should have its outer angle rounded off, and the interior angle checked down about 4 inches, to receive and support the footpath pavement.

"The gutter and curb-stones should not be less than 3 feet in length, and axed on the faces which are seen; their joints being arris chisel drafted, or neatly axed, so as to make a close joint, and the whole set in good water-lime mortar.

"*Footpath pavement* should be laid in regular courses, and if possible the stones to be of the length of the whole width between the curb-stone and parapet wall; they should never exceed three stones in width; where this cannot be accomplished, the joints should alternate, and the surface be neatly broached, and made with an inclination of an inch to 3 feet, or 1 in 36, towards the curb-stone, the top of which should be laid 6 inches above the gutter stone.

"*Road concrete.*—The stone shivers and dry rubbish having been well pounded, and filled in between the wing walls, the whole is then to be covered with a bed of lime and gravel concrete well mixed, in the proportions of four measures of clean gravel to one measure of water-lime mortar, used fresh. This bed of concrete should not be less than 9 inches in thickness on the outside, and 12 inches in the middle of the roadway, the surface forming a uniform curve. Upon this may be laid the paving or metal for the road.

"*Drain pipes*, of iron, 6 or 8 inches diameter, are to be introduced to carry off the water, passing through the arch-stones of the bridge, and continued down the abutments."

Number and dimensions of bridges built under the Highland Road and Bridge Act of 1803, by Thomas Telford; —

1,075 bridges of one arch, varying from 4 feet span up to 65 feet, and affording a water-way of 10,198 feet.
13 bridges of two arches, with a water-way of 643 feet.
16 bridges of three arches, with a water-way of 1236 feet.
2 bridges of five arches, with a water-way of 522 feet.
11 others with forty-three arches, and having a water-way of 2387 feet.

Making a total of 1117 bridges, 1202 arches, and 14,686 feet of water-way.

"*General specification for the bridges.*—Required that they should be built over each river or stream with stone and lime mortar, and that the foundations should be sunk to and laid on the rock, wherever practicable; where this could not be done, then the foundations were required to be sunk 2 feet at least below the lowest part of the bed of the river; and wherever the ground was loose a platform of timber was to be laid under the foundations of the masonry; this platform was to consist of two thicknesses, of 3-inch plank, laid crossing each other, and if necessary a row of pile planking driven all round the outside. If the ground was hard, instead of this timber platform, an inverted arch or pavement was to be laid and wedged between the abutments, the entire width of the bridge, and well secured above and below by means of rows of piles sunk deeply into the bed of the river.

"The span of the arch to be according to the table annexed. The breadth of the road-way between the parapets to be 18 feet in the narrowest part.

"The parapets to be not less than 18 inches in thickness, of the height mentioned in the table, coped with hammer-dressed stones, set on edge in lime mortar, not less than 9 inches in depth, with a large stone at each extremity of the parapet.

"Wherever the ground required them, retaining walls are to be used, of dry stone of sufficient thickness, as described for breastwork, to support the made-up ground, and these walls to run from the extremity of the parapets into firm ground, unless the distance exceed 20 yards.

"When the bridges are not set upon rock, bulwarks of dry stone are to be introduced above and below the abutments, 10 yards in length. The dimensions of the masonry to be as set out in the table below.

"The spandrills of the arches to be filled with stone or coarse gravel, so that the rise and

fall of the roadway over the bridge should not exceed one in twenty-four in the steepest places.

"The roadway to be formed of properly cleansed gravel to cover the top of the arch at least 14 inches.

"Each bridge of one arch to be built so that the parapets when finished should have a curve horizontally of not less than 3 feet in 36 feet in length; and all the bridges to batter vertically at least 1 foot in 12 of height, and this height also to have a concave curve of 4 inches.

Span of Arch.	Rise of Arch.	Depth of Arch Stones.	Height of Abutments from Bed of River to the Springing.	Thickness of the Walls of the Abutments on an Average.	Length of Parapets from the Face of Abutments with Wings under.	Height of Parapets above the Crown of the Arch.	Thickness of Spandrills and Wings on an Average.	Thickness of the inverted Arch.
Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
4 0	1 6	1 0	2 6	1 6	9 0	1 2	1 6	0 9
6 0	2 0	1 0	2 6	2 0	10 0	2 2	1 6	1 0
8 0	3 0	1 2	2 6	2 0	12 0	3 2	2 0	1 0
10 0	3 6	1 3	3 0	2 6	12 0	3 2	2 0	1 0
12 0	4 0	1 4	3 0	3 0	14 0	3 2	2 6	1 0
18 0	6 0	1 6	3 0	4 6	18 0	3 2	2 9	1 4
24 0	8 0	1 9	4 0	5 0	24 0	4 2	2 9	1 4
30 0	12 0	2 0	4 0	5 6	30 0	4 2	3 0	1 6
50 0	15 0	2 6	6 0	6 6	36 0	4 8	3 6	1 6

"The spandrills were all to be filled up between the outside walls with solid masonry, above the level of the springing of the arches, up to one-third of the height of the rise of the arches."

Dunkeld Bridge, erected in 1809, has five large arches, and two smaller ones. The middle arch is 90 feet span, with a rise of 30 feet; the two adjoining arches are 84 feet span, and the other two 74 feet; the two smaller or land arches being only 20 feet span. The breadth, measured across the soffite of the arch, is 27 feet, that of the roadway between the parapets 25 feet. The thickness of each of the two middle piers is 16 feet, that of the two next 14 feet, and that of each of the two side piers 20 feet, and of the land abutments 7 feet. The cost of this bridge was 13,361*l.*

Allness Bridge, on the Fearn Road, county of Ross, has one stone arch of 60 feet span and 20 feet rise.

Helmsdale Bridge, on the Dunrobin road, Sutherland, has two stone arches, each 70 feet span, with a rise of 25 feet.

Conan Bridge, near the town of Dingwall, consists of five arches of 65 feet, two of 55 feet, and two of 45 feet span. The cost was 6,854*l.*, and the water-way 265 feet.

Potarch Bridge, over the River Dee, near Kincardine O'Neal, has three arches, the middle spanning 70 feet, the others 60 feet.

Lovat Bridge has five arches, the middle spanning 60 feet, two 50 feet, and two others 40 feet, the cost of which was 8802*l.*; the water-way 240 feet.

Ballater Bridge, over the Dee, has five arches, the middle one spanning 60 feet, and the total water-way being 238 feet. The cost was 4224*l.*

Alford Bridge has three arches, the middle arch spanning 48 feet, the others 40 feet; the whole water-way being 128 feet, and the cost 2000*l.*

Fairness Bridge has three arches, the middle spanning 55 feet, the other two 36 feet, the total water-way being 127 feet; the cost was 1255*l.* These were all erected by Mr. Telford.

Bridge at Edinburgh, over the valley of the North Loch, was built by Mr. Mylne, and consists of three arches each 72 feet span, and two smaller 20 feet span. The height from the surface of the ground to the springing of the arches is 17 feet 6 inches; the arches are semicircular, and the thickness of the voussoirs 2 feet 9 inches. From the top of the voussoirs to the top of the parapet is 9 feet 9 inches, making the entire height 65 feet. The breadth across the soffite of the arches is 42 feet 3 inches. The cornice and parapet curve downwards, which produces a bad effect.

Bridge over the Teviott, erected by Mr. Elliot, consists of three arches; the middle spans 65 feet, and rises 17 feet: the whole are segments, and the width over the parapets is 23 feet. This bridge was completed in 1795.

Peas Bridge, on the road from Berwick to Edinburgh, was designed by David Henderson; it has 4 arches, the span of the greatest being 55 feet, and the entire height of the bridge 124 feet; it is constructed over a deep dingle.

Bridge at Fochabers, over the Spey, was built by Mr. G. Burn; it consists of four arches, the two in the middle span 95 feet, and the breadth over the parapets is 21 feet 6 inches: as the number of arches are here even, a pier occupies the middle of the river.

Hutcheson Bridge, over the Clyde at Glasgow, erected after the designs of Robert Stevenson of Edinburgh, consists of five segmental arches, whose radius is 65 feet. The middle arch spans 79 feet, and its versed sine is 13 feet 4 inches. The arches on each side are 74 feet 6 inches wide, and the outer 65 feet, and their versed sines are 11 feet 9 inches and 8 feet 8 inches. The rise of the road from each side is about one in thirty, and the breadth of the bridge, measured over the soffite of the arches, is 38 feet.

The entire width between the faces of the abutments is 404 feet, 358 feet being occupied by the arches, the rest is taken up by the piers. The bed of the river consisting for 27 feet of gravel, sand, and mud, cofferdams were made use of, composed of two rows of piles 3 feet apart, filled in between with clay.

The cost of this bridge was 23,000*l*. The voussoirs measure in length 3 feet across the soffite; the depth of the keystone is 3 feet 6 inches, and the other voussoirs gradually increase in dimensions, being at the springing of the central arch 4 feet 6 inches; the others diminish in proportion.

One of the earliest bridges constructed across the Clyde was built by William Rae, who about the middle of the fourteenth century was Bishop of Glasgow; the next was the Broomielaw, opened in the year 1772; and the importance of the navigation between Greenock and the city, and the improvements made around Paisley, rendered necessary the Hutcheson Bridge, so called from two brothers, George and Thomas, who died in 1640 and 1641, bequeathing considerable sums of money to purchase land, the rental of which was to be appropriated for the relief of the aged and infirm, and also for the education of the young.

Hutcheson Bridge is a fine piece of construction; the stones used are all of excellent quality; the heights of the courses vary from 12 to 16 inches, and are composed of alternate headers and stretchers; the former bond into the wall, 3 feet 6 inches, and on the outer face are not less than 2 feet in length; the stretchers are 2 feet in breadth on the bed, and 3 feet 6 inches on the outer face; the beds are droved round the outward edges to the breadth of 3 inches, and broached with mallet and iron within these draughts. The outward faces of the courses, below the level of summer water mark, have 1½ inch chisel draughts round the edges, and are picked and hammer-dressed between; above the summer water-mark the face work of the abutments and piers are neatly broached, and the horizontal joints are chamfered to the breadth of 1 inch on the beds and faces; the hearting stones of the abutments and piers have also 1½ inch chisel draughts round the edges of the horizontal beds, and are broached between, the vertical joints being dressed square with the pick or hammer.

The springing course of the arches is 4 feet in thickness, and on the piers as well as the abutments consist of three rows of stone; the two outer are worked off on the faces to form the voussoirs, which have a soffite 9 inches in breadth, and a bed of 3 feet 6 inches on the pier; no stone being less in length than 2 feet 6 inches. On the piers the middle or closing row of stone is laid in two courses, and exactly fills the space up.

The beds of all the voussoirs have their edges all droved round to the depth of 3 inches, between which draughts they are broached. The end joints are all chisel draughted and broached between; and the face work of the soffites is broached, and the bed joints across the arches; and the heads of the ring courses are chamfered to the breadth and depth of 1 inch on each side of the soffites.

Stone Bridge, over the Whitadder at Allanton, executed from designs furnished by Messrs. R. Stevenson & Sons, has two arches, each spanning 75 feet, with a versed sine of 11 feet 6 inches, being segments of circles, the radius of which is 66·89 feet for intrados and 72·42 feet for extrados. The voussoirs are 3 feet deep at the springing, and 6 inches less at the crown. The breadth of the bridge measured across the soffite is 22 feet 1 inch, between the parapets 20 feet, and the width of the roadway 15 feet. The foundations are on a sandstone rock, and the whole of the masonry is of broached ashlar; the stone generally used is a soft red sandstone, and the mortar one part lime, two parts sand. This bridge was completed in 1842, at an expense, including its approaches, of 6,058*l*.

Railway Bridges.—It would not be possible to enumerate the whole of the viaducts constructed since the introduction of railways. Structures in timber, brick, iron, and stone of various designs have been erected, and in some instances there is a novelty of principle accompanied by great boldness of execution.

The brick bridge at Maidenhead, constructed by Mr. Brunel for the Great Western Railroad, is one of the best examples in that material; it is composed of two elliptical arches spanning the Thames, each 128 feet, with a versed sine of 24 feet 3 inches. The piers between the two arches are 30 feet in width. The arch is 5 feet 3 inches high in the middle, and gradually increases in thickness towards the abutments; at about ¼ from the springing it is 7 feet 2 inches high.

The width of the bridge, measured on the soffite, is 36 feet, and of the piers, in the same direction, 43 feet 3 inches. The clear width between the parapets is also 36 feet, as the thickness of the parapet walls is obtained in the projection of the cornice.

Six longitudinal walls rest on the back of the brick arch, which carry the platform on which the rails are fixed. Besides these two grand brick arches on each bank of the river are four others with semicircular heads; that on the abutments spans 21 feet, the six others are each 28 feet.

Skew Bridges. — One on the London and Birmingham line carries the railway 23 feet 7 inches above the level of the road, and the angle it makes is 32°, the square span of the arch being 21 feet, and the oblique span 39 feet 8 inches. The arch, 2 feet 6 inches thick, is the segment of a cylinder, the internal radius of which is 12 feet 6 inches, the versed sine 5 feet 8 inches. The angle at which the coursing joints of the soffite cross the axis of the cylinder is 53° 25′, and that of the extrados is 58° 15′; the angle of the voussoirs consequently is 4° 50′. The joints of the face of the arch all converge to a point, 32 feet 6 inches below the axis of the cylinder, or 45 feet below the crown of the arch.

Midland Counties Railway, presents another variety of skewed brick bridge, the span of which is 42 feet 6 inches, and versed sine 11 feet; the whole consists of six arches, 2 bricks in depth, and 4 feet in thickness: the total width of the bridge, measured through at right angles with the face, being 24 feet.

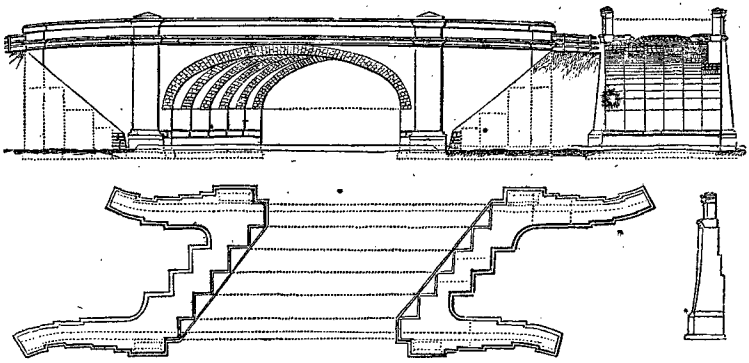


Fig 472. BRIDGE OVER THE LOUGHBOROUGH AND STANFORD ROAD.

Another skew bridge on this line, over the Nottingham and Sawley Road, is of a different construction; the whole depth of the bridge, measured square with the face, is 27 feet, and the span 53 feet, with a versed sine of 7 feet.

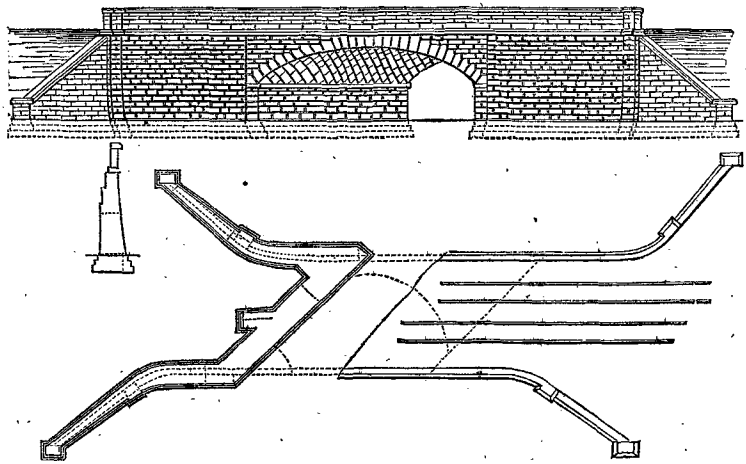


Fig. 473. BRIDGE OVER THE NOTTINGHAM AND SAWLEY ROAD.

A great variety of skew or oblique bridges has been erected in brick for several railways, and by means of such arches the engineer has been enabled to avoid all awkward and injurious turns in the lines of rails to be carried over them; the lines of pressure are

delivered upon the abutments, and are generally contained in vertical planes, lying parallel to the sides of the roadway: such arches, intersected by numerous planes, transmit their pressure from one to the other, in a direction perpendicular to those pressures.

Bridge over the Ouse near York, constructed for the Great North of England Railway, consists of three arches, each 66 feet span; the piers are 10 feet in thickness, and the arch measured on the soffite 28 feet 7 inches. The thickness at the keystone is 3 feet 6 inches, and the voussoirs gradually increase towards the springing.

This is another excellent example of a bridge of three arches, the curvature of which in the outer is continued to the footings of the abutments; by which means the voussoirs at the springing are extended considerably in length. The centering made use of was well

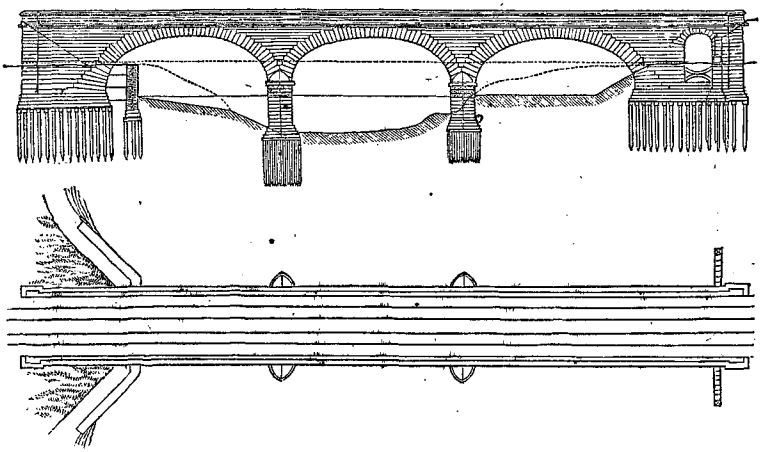


Fig. 474. BRIDGE OVER THE OUSE; PLAN AND ELEVATION.

put together, and rested upon piles inclined towards the foundations on which they were placed; and the piers are capped with a single stone, from which the voussoirs commence, their thickness gradually decreasing towards the key, which lessens the pressure and increases the strength of the arch. The starlings or cutwaters are formed of two arcs of

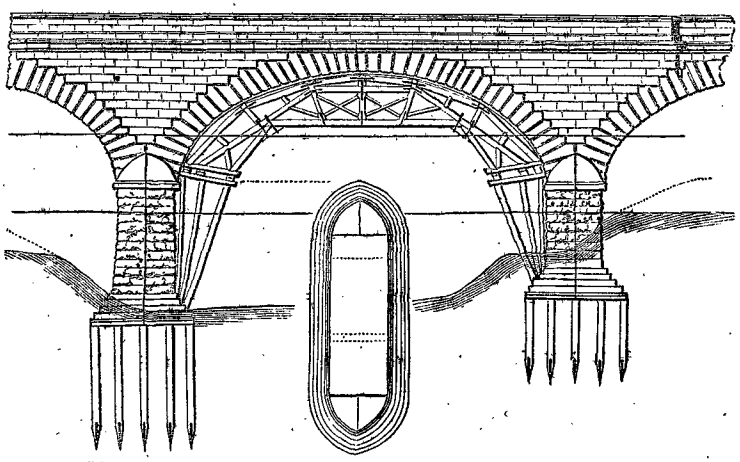


Fig. 475. BRIDGE OVER THE OUSE; ARCH AND CENTRE.

60 degrees, described from the two angles of the piers, which perhaps are the best adapted for a rapid stream. It is generally supposed by most practical men that the strongest angle is that formed by an isosceles right-angled triangle, having its right angle facing the stream.

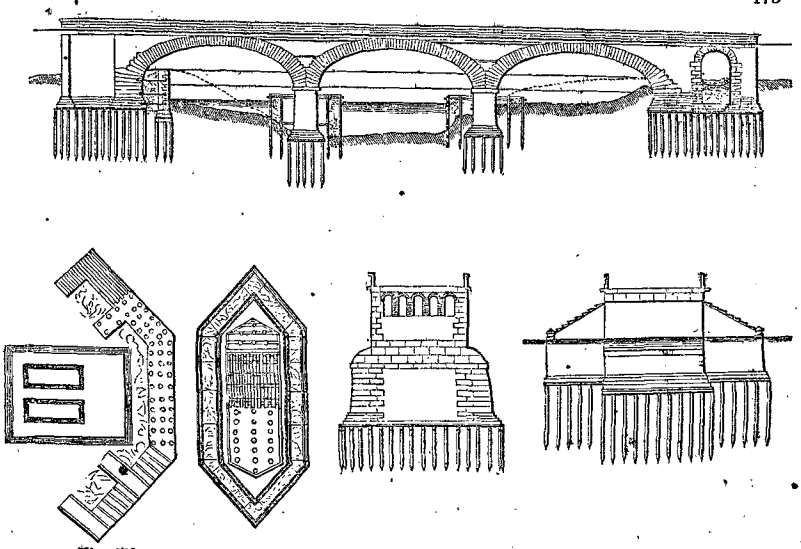


Fig. 476. BRIDGE OVER THE OUSE, SECTIONS AND PLAN.

Bridges in Ireland. — *Queen's Bridge*, Dublin, over the Liffey, was finished in the year 1768, under the superintendence of Colonel Vallency; it consists of three arches, that in the middle spans 46 feet, and each of the others 35 feet; the piers are 7 feet in thickness, and the breadth between the parapets is 35 feet.

Essex Bridge, in 1753, was commenced after a design of Mr. George Semple; it consists of five arches, one 58 feet span, three of 45 feet, and one of 37 feet; the thickness of the piers on each side of the centre arch is 6 feet, the breadth between the parapets 48 feet; a very interesting account of the building of this bridge was published by the architect in 1780.

Previous to the work being commenced, the above ingenious architect directed his attention to the nature of the foundations of the old bridge, and found that where the piers were built upon a bed of sharp gravel, the lime had so penetrated that the whole surface seemed petrified or converted into stone; he then enters fully into the nature of the construction of walls, called by the Italians *Reimpiuta*, or cofferwork, and recommends that no stone used among the stuffing should in weight exceed 1 pound; but he more particularly dwells upon the nature and properties of lime, mortar, and grout, details many experiments that he had made, and informs us that he had heard a Scotch mason affirm, that in 100 years good mortar would become as hard as stone. In these descriptions we have the author's opinion upon the manner adopted in building the walls of churches and castles. "After the masons had laid the outside courses with large stones laid on the flat in swimming beds of mortar, they hearted their walls with their spawls and smallest stones; and as they laid them in, they poured in plenty of boiling grout, or hot lime, liquid among them, so as to incorporate them together, as if it were with melted lead, whereby the heat of it exhausted the moisture of the outside mortar, and united most firmly both it and the stones, and filled every pore, and so set that it grew hard immediately; and this method was taught to our ancient masons by the Romish clergy that came to plant Christianity in these countries; and this mortar," he affirms, "so run together, was harder to break than the stones that were imbedded it." There are many very sensible and useful remarks contained in his curious work, which relate to a variety of subjects connected with constructions in water, and which would interest the civil engineer.

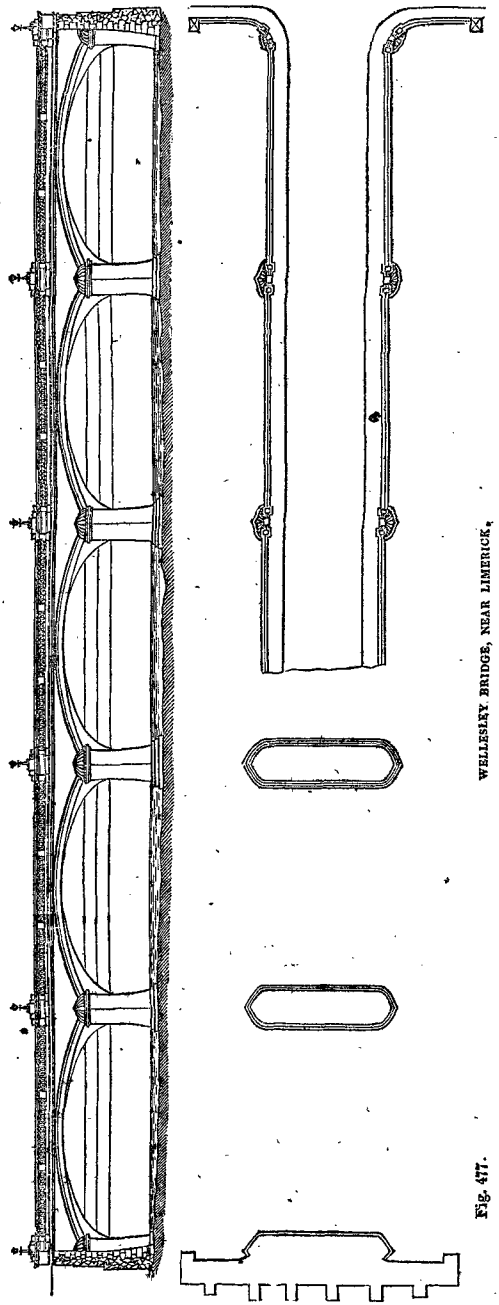
Sarah's Bridge was built by Mr. Stevens, in 1792; it consists of one arch, 110 feet span, with a rise of 22 feet; the breadth between the railing is 37 feet.

Carlisle Bridge consists of three arches, the middle 50 feet span, the others 40 feet each; the thickness of the piers 10 feet, and the breadth between the parapets 63 feet.

Wellesley Bridge, at Limerick, erected after the designs of Alexander Nimmo, consists of five segmental arches, each 70 feet span, with a versed sine of 8 feet 6 inches; the piers are each 10 feet in thickness, and the soffite of the arch, measured from one face to the other, is 43 feet.

This bridge bears considerable resemblance to some of those constructed by Perronet,

where the archivolt is made to partake of a different sweep to that of the soffite, in order to produce a greater lightness in the elevation; or the soffites of the arches are shaped to suit the contracted vein of water as formed in the entrance or exit of pipes. The roadway over this bridge is maintained throughout at a perfect level, and there is no break or distortion in the cornice or the balustrade: we have seen in some of those constructed by Mr. Rennie how much attention was paid to have the lines perfectly horizontal, and although in France the slopes to the sides of bridges had been long abandoned, it was some time before the system underwent a change in England: in the bridge at Limerick the approaches are well managed, and the effect of the structure is much to be admired. The piers are elegantly capped and proportioned, and for the omission of columns, or of any useless ornament, the engineer deserves great praise: simplicity and proportion, coupled with good construction, are all that have been aimed at, and in this example we find nothing extraneous. The section through the arch and pier shows the construction, and that every means has been adopted to lighten the weight, and to strengthen the parts which sustain it: the curvature of the intrados meets with a gentle inclination on the sides of the pier, and the alteration from the perpendicular line is a great improvement, not affecting the width of water-way, but adding to the strength of the footings of the piers.



WELLESLEY BRIDGE, NEAR LIMERICK.

Fig. 477.

It is not possible to enumerate all the stone and brick bridges that have been constructed within the last half century,—those for the canals and the railroads alone amount to several thousands: it is enough, perhaps, for our purpose to have described examples of each variety, and thus exhibited the different phases of the science.

Every county in the kingdom has had its civil engineer, and some of the works executed are highly creditable, although they do not generally show an acquaintance with the higher principles of construction. To the late Mr. Rennie we stand indebted for our most beautiful bridges, and for the introduction of scientific principles: that eminent engineer had

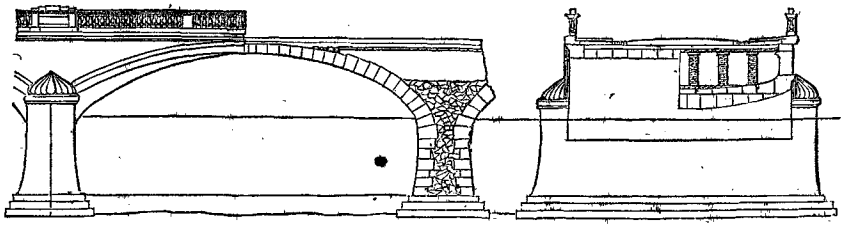


Fig. 478. SECTION OF ARCH AND PIER.

attentively studied the various forms of curvature given to the arch by the French and Italian architects, but did not adopt either until he had practically tested the properties of all. The result of his observations is seen in the magnificent bridges that cross the Thames, which are monuments of his constructive skill; they have never been equalled, and cannot be surpassed. England may certainly now boast that her engineers have advanced in the knowledge of the principles which direct the bridge-builder; in tracing the history of the art through the last six or seven centuries, we find not a gradual progress, for it does not appear until the construction of Westminster Bridge, or a little time previously, that much change had been made, or that the proportions for the stones forming the voussoirs had been at all considered; and when Semple published his work very little was known. The bridge at Blackfriars possesses considerable merit, and indicates a march in the theory of construction; but until the latter end of the last century the science was not matured. We have only to compare the old with the new London bridges, and we shall be satisfied that in the former we have construction alone, whilst in the latter it is directed by highly scientific principles, producing an effect which is admired by the most unpractised eye, with an immense economy in the materials.

Iron Bridges.—Before we proceed with a description of several constructed previous to the close of the eighteenth century, we shall endeavour to show the opinions of some of the learned men on the principles of such construction; and we cannot do better than refer to a report which was laid before Parliament on the subject of one of the boldest conceptions ever formed, which was to span the Thames by a single arch of cast-iron, the segment of a circle 1450 feet in diameter. This arch was to have an opening of 600 feet, with a versed sine of 65 feet. It was to consist of seven ribs, having a roadway over the centre, 45 feet in width, and which towards the abutments was increased to double that dimension. It was computed to require for its execution 6500 tons of iron, 432,000 cubic feet of granite, and 20,029 cubic feet of brickwork for its abutments; the total cost of which was estimated at 262,289*l.*

The originality of such a cast-iron arch was greatly admired, and Messrs. Telford and Douglas, who had presented the designs, were called upon to submit them to several scientific and practical men, that their opinions might be taken before any risk was encountered in the construction. To keep the attention of those consulted to the subject, several questions were drawn up, and their answers will enable us to form a tolerably clear idea of the state of science at that time in England.

Some licence has been taken with the arrangement of the report, and portions are omitted, those only being retained which are applicable to iron bridges.

The Parliament, however, after having received the various opinions, thought the experiment far too bold, and the bridge was not erected.

The first question was, What parts of the arch are to be considered as wedges which act on each other by gravity and pressure, and what part merely as weight, acting by its gravity only, similar to the walls and other loading commonly erected on the arches of stone bridges; or does the whole act as one frame of iron, which cannot be destroyed but by crushing its parts?

Dr. Nevil Maskelyne, the Astronomer Royal, answered this question, by stating, that he considered the whole of the iron bridge as one great frame of iron, which could be destroyed only by breaking or crushing its parts by the weight of the whole, or by weights laid on it, or by passing over it. However, the wedging of the parts together, by the convergence of the frames to their centre of curvature, may be useful to secure the bridge from the consequence of the decay or failure of any of the parts in future times, as well as for the convenience of easier putting it together.

The Rev. A. Robertson, Savilian Professor of Geometry, supposed A B D E F to represent the bridge, *b d e* the under part of the arch, and *a c f* the upper, *b d e* and *a c f* being concentric. Let *c d*, *n k*, *m h*, and *l g*, &c. be straight lines, and let the direction of each be to the centre of the circle; then will *c n k d*, *n m h k*, *m l g h*, &c., represent portions of the arched part of the bridge, and these portions only can be considered as wedges.

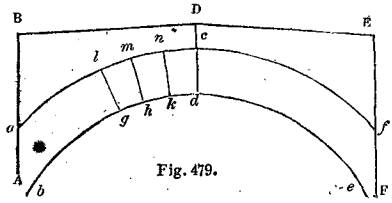


Fig. 479.

It is evident, that the strength of the arched part of the bridge will be as the length $c\,d$ of the side of one of these wedges; as is the excess of $n\,c$, the upper or back part of the wedge, above $k\,d$, so will it be increased as $c\,d$ is lengthened. The height of d and D the highest point in $b\,d\,e$, and the highest point of the bridge above the horizontal line A F, limit the lengthening of $c\,d$, the side of the wedge. These wedges act upon one another by their own gravity and the gravity of the matter over them. The sides $c\,d$, $n\,k$, &c., of the wedges being accurately directed to the centre of the circle, occasioned him to consider the whole of the arched part of the bridge equally strong, as one piece of cast-iron, of the same form, dimensions, and weight; and that if the iron work above the arched part of the bridge be firmly connected together, and with the arched part, the whole may be considered as one piece of cast-iron, of the same dimensions and weight.

Mr. Playfair, Professor of Mathematics at Edinburgh, in his consideration of this question, remarked, that iron bridges admit of being constructed more exactly on the principles of equilibrium than stone bridges, but that the equilibrium may be more safely dispensed with in the former than in the latter; as the frames of iron in the form of truncated wedges may be made of any depth, so that the whole mass from the interior to the exterior curve of the bridge may consist of such wedges, and every single ounce of matter may contribute to support itself. In bridges of stone, on the contrary, the depth of the wedges or key-stone is necessarily limited to a few feet. All the superincumbent load, being merely dead weight, the exact distribution of which, according to the law required by the equilibrium, is extremely difficult, or rather impossible to be attained. The truth of the second assertion, that an exact equilibrium of the parts may more safely be dispensed with in bridges of iron than in bridges of stone, depends partly on this, that the materials which compose the former are much lighter for their strength than those which compose the latter, iron being hardly three times heavier than stone, and more than an hundred times as strong. It depends also on this other circumstance, that the whole mass being connected, especially if it consist of truncated wedges, extending from the interior to the exterior curve of the bridge, even though an exact equilibrium does not take place, every part of the mass contributes its share to the support of the whole.

The whole bridge, if we except the road over it, the parapet, and the framework, that immediately support them, is to be regarded as a system of wedges, resting against two immovable abutments, each of which wedges, whether the whole be in perfect equilibrium or not, contribute to its own support. This holds in the strictest sense in this instance, as the bridge consists of 63 wedge-form frames of iron, each 10 feet thick at its lower extremity, with the inclined sides all converging to the same point. This is without doubt a most advantageous construction.

Mr. J. Robeson, Professor of Natural Philosophy at Edinburgh, observed that in this question was involved several others, and that taking the whole structure together, he thought that it must not be considered as in the condition of an arch of masonry, each part acting merely by its weight, and the whole maintaining its form by being equilibrated; and observed, I see, however, that the ingenious inventors have had this very much in their thoughts, because the profile is plainly divisible into several arch frames of different radii, all having a common tangent at the crown. The undermost may be considered as the main arch, which the superior ones are only intended to relieve, while they stiffen it, and connect it with the road-way. But in this way of considering the structure, it is very far from being fit for supporting itself by mere equilibrium. The main arch is abundantly able to do this, if alone, because a catenusea of the same span and base will not deviate from one of its circles 3 inches in any part. But when the upper arches are taken in, the road at and towards the haunches is vastly too great. I do not think, however, that this great want of equilibrium will make the bridge unable for its load, because the crown is still by far the weakest part, the total strength at the haunches being vastly greater than is necessary. I think the bridge abundantly strong, if united in a proper manner, but I think that it is rather in the condition of a frame of iron consisting of two pieces, leaning on each other in the middle. I think that our mathematical theories of arch vaulting are extremely defective, and that their defects arise from the very anxiety of the mathematicians to make them perfect. The joints are supposed to be without cement, perfectly polished, and therefore everywhere perpendicular to the curve or soffite of the arch; and the mutual pressure is supposed to be everywhere perpendicular to those joints. But the mutual friction of the parts and the connection of straps or of joggles introduces a force which has no place in those theories. It enables a load on one part to act on a far distant part transversely with the energy of a lever. By attending carefully to the way that old arches fail,

I think that they almost all act like the rafters, D A, B E, of a mansard or kerb roof, from which the middle tie-beam has been taken away. The crown breaks in by the opening below and crushing above, and it springs at some intermediate points, by the joints opening there on the upper side. Sir Christopher Wren considered an arch entirely in this way, and makes no use whatever of the mathematical theory of cymlibration, although then carefully studied by the great mechanicians. The drawings do not clearly show how the different arch-stones or frames are united, yet plainly point out something like joggles in one frame fitting concavities in the one adjoining, by which they are prevented sliding on each other. I highly approve of this plan, because it connects at least half of this rib of frames: as a straight line can be drawn through, causing it to act as one rafter, I am confident that this ring alone, if considered as consisting of six pieces, the joints of which *a b c* are connected with the roadway by uprights, *a a'*, *b b'*, and truss rafters, *a g*, *f g*, *a h*, *b h* abutting on the arch, would make it firm enough, stiff enough, and a great deal lighter than by the plan proposed. But I do not mean to prefer this method, because, although six points of bearing may be perfectly sufficient, it is far preferable, with so brittle a material as cast-iron, to make the bearings as numerous as possible, that no one point may be much more strained or compressed than another; yet I think that this is overdone in the proposed plan, and that it might be much lighter in the haunches.

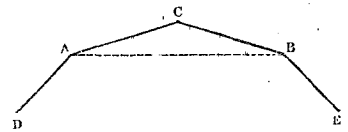


Fig. 480.

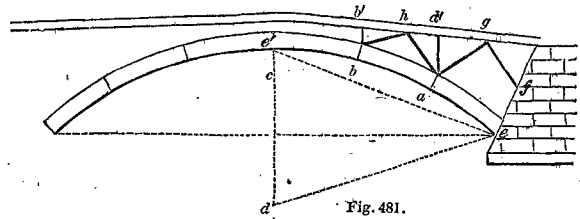


Fig. 481.

I should certainly construct the main or lowest ring as an arch of equilibration, making each of its frames bear on its neighbour, as a stone in an arch of masonry. I think that any cement would be inefficient, and would be hazardous in the extreme; I know no practicable cement whose cohesion will be of any significancy, none that will not be a little compressed by the enormous horizontal thrust of near 10,000 tons. The consequence of the compression, by the arch taking its set, will be almost certain destruction, as I shall show by-and-by. The frames should all abut on each other with perfect accuracy. If they are to have this form, the radial joints must all be ground on each other lengthways, so that they may touch all over; should cement be put on such a joint, the smallest hard bit about the middle would cause the piece to snap without remedy. Grinding will procure a full contact and bearing, therefore the joggles should be loop pieces, like pound balls, that the grinding may be practicable. Perhaps this form may be still more secure against snapping, and not unsuitable to the style of ornament, which is very pure Gothic. I own that I prefer Mr. Burdon's construction of the ring, as the most susceptible of accuracy in the execution, the firmest union, by means of the wrought-iron straps, and perfectly free from snapping. I foresee immense difficulty in casting everything true, so as to have the radiated joints all straight, and all bearing, and for this reason am disposed to prefer a construction with loose pieces, butting endways, like rafters. The different expansion of different fonts of iron by heat will have some effect here; whenever a joint seems open, or not in an exact line with the rest of that radial joint, it should be filled up with a plate of good copper. A forged iron plate would perhaps exfoliate with the weather.

I look upon this circumstance of accurate joining as the most important of all in this particular construction, and I apprehend that it was this difficulty that induced Mr. Burdon to fill up the haunches of his arch at Wearmouth with a series of circles, which serve merely to prevent the main arch from rising in the haunches, and to support the roadway. But if it can be attained, the bridge will be both stiffer and stronger.

That the hazard from the compression of cement or the closing of bad joints may clearly appear, we must now consider the weight of the whole, and the different thrusts excited in its different parts. I consider it as two masses resting on the abutments, and leaning on each other in the middle; I suppose the carriage-way to have 2 feet of gravel, each cubic foot weighing 109 pounds. The footpaths may be paved hollow with free-stone, so as not to require more than 18 inches in thickness. One half of this, including the increasing width at the ends, will weigh about 1800 tons; this added to 3250 tons of iron work makes 5050 tons. I think that its centre of gravity is situated at nearly two-fifths of the half-breadth of the arch from the abutments, that is, at about 120 feet. We have, therefore,

5 : 2 = whole weight : vertical weight at the crown, 13 : 30 = weight at the crown : horizontal thrust.
65 : 60 = whole weight : horizontal thrust.

Therefore the proportion of 13 to 30 is that of twice the height (65 feet) to the half of the span (300 feet). As the same load at the crown is produced by the other half of the bridge, this must be doubled, or say as 65 : 60 :: 10100 tons : 9323; 10,000 tons being the whole weight, and 9323 the horizontal thrust. Some mathematicians consider the horizontal thrust as only the half of this quantity, but this is a mistake.

Now this thrust is the same in every part of the arch, as is well-known; therefore the whole of this thrust is borne by the middle joint of the seven ribs, and amounts to above 1300 tons on each joint. Did the whole joint bear alike, there would be little danger, but when the arch is set up on its mold, and the middle frame or key-stone nicely fitted in, and the scaffolding removed, every thing comes into a new situation, all settles. The joints are squeezed close, and even the solid metal of the whole bridge suffers a compression: this is equivalent, as far as relates to the figure of the arch, to a yielding of the abutments. One inch of compression in the half arch will cause the crown to sink nearly 5 inches. A total compression of 3 inches in above 300 feet is no unreasonable supposition; this will produce a sinking of 15 inches at the crown: should this take place without a change of shape in the half arch, it is evident that the enormous pressure of 9000 tons will be borne by the upper end of the joints of the key-frame, and the lower end of the same joints will be much less pressed. The frames will be hanging by their upper angles, and the upper rail of the frame will be strained with the greatest part of the thrust. I should fear exceedingly that so brittle a substance as cast-iron would be very apt to chip off at the upper angles of the frames at the crown of the arch; if any cement be admitted into the joints, I apprehend that the sinking and the inequality of pressure will be vastly greater. If, indeed, the intermediate half arch between the crown and the abutments shall bend a little, this will tend to equalise the pressure on the joints at the crown. It may even bend so much, if ill-joined, as to make the middle joints bear most on the lower angles; but this is highly improbable, because the general shape of the half arch makes it almost incapable of bending, even though the radial joints are not very accurate.

The method that occurs to me as the most effectual to prevent this risk is to form a middle piece of the arch, so as to keep the mutual pressure diffused over the whole joints, even though the whole arch should settle considerably. Thus, instead of making the joints straight lines, I would make them arches of circles of about 25 or 30 feet radius, or still less radius and more curvature, so as to lengthen as much as possible those joints which are to bear so great a strain. I would not, however, make more than two of these joints, because if these be allowed to slide a little on each other, having no joggles, the joints will keep close, like the joints of a sector. It will not hurt the style of ornament if this middle piece should differ greatly from the rest. I would also make this middle piece (or key) entirely of wrought-iron, as much better suited for preventing chipping at the angles, and for affording fixtures for diagonal ties, which may be found necessary for stiffening this weakest part of the arch. For if such ties or struts be attached to parts of cast-iron, and much greater strain be exerted there than in other parts, they are in great danger of snapping. It should be carefully kept in mind in this structure, that when a bar is sustaining a very great compression endways, or in the direction of its length, it is more easily broken across by any transverse strain. I have made many experiments on this kind of strain; a piece of white marble ¼ inch square and 3 inches between the props bore 38 pounds. When compressed endways with 300 pounds, it broke with 14½ pounds. The effect is much more remarkable in timber and softer bodies, but is considerable in all, and this circumstance will make it hazardous to employ ties in the bridge. We extend their action to considerable distances, so as to create great strains on particular points. Yet I think that ties may be usefully and safely employed, diverging from the lower side of this middle piece, and connecting it with several frames on each side, in order to stiffen, by supporting the middle points.

The part of the arch which requires the greatest accuracy in the construction is about 80 or 100 feet on each side of the middle and the lowest ring of frames all over, if those be close-jointed; the rest is free from all risk. The portion mentioned of the middle must be carefully jointed up to the roadway, so as to make one mass; this being set on the arch-ring will tend to force it up a little at the haunches; but the work above it will effectually prevent this, although not executed with such accuracy.

In the forming of this profile, by which the haunches are filled up, it is asked whether it is more advisable to cast the frames in long masses or in smaller frames. In carrying the principle of masonry through the whole, one is prompted to cast the pieces, so as to interrupt the lines of joint, or to break joint, as masons call it. I should think this hazardous. If one half of a radial joint be closer than the other half, there is a great risk of the sides of the frames snapping in the middle. Plates of copper should be employed for making up all such deficiencies, or even tin-foil, such as is used for the silvering of mirrors; perhaps some way might be fallen upon to apply heat to the pieces when set in their places, so as to

make the tin take hold of the iron, but this is not necessary. The great pressure and the bullet joggles will prevent all change of figure.

After all, I own I still prefer Mr. Burdon's construction of the arch. His method of combining the abutments of the cast-iron rails of his frames with the wrought-iron straps seems finely calculated for procuring a close union of the parts. A judicious artist will perceive, that by a proper forming of the holes in the three pieces (the cast-iron rail between the two wrought-iron straps), the drawing of the keys into these holes will draw the two cast-iron ends closer together, and press them hard into each other. Thus, when keys are drawn into the holes, the two parts of the cast-iron bar which is between the straps will be forced hard together. I observe, also, that Mr. Burdon's arch has three rails, and the London arch has but two; at least the middle rail of pierced work does not seem to form a line of abutment supporting the middle of each subjoint. I think that this mode of framing at Wearmouth might be extended to the next circle, which is in the middle of the Gothic arcade. The effect of the straps which form this circle would be prodigious in strengthening the whole.

Dr. Milner on this question supposes the whole mass of the bridge to be cut into a great number of thin slices, bounded by planes parallel to each other, and all of them parallel to the plane of the arch of the bridge; then it may be said, that all those parts of the iron work, whether they be called ribs, bars, rods, braces, frames, or by any other names, all that can be properly considered as lying in the above-mentioned planes, or so extending between any of them in the direction of the said plane, as to contribute to the formation of the arch, and also to the strength of it, considered as a geometrical curved line, or rather as a bent iron rod of small thickness; all the parts of the work coming under this description act as wedges, both by gravity and pressure, but all the parts which serve merely to bind together the above-mentioned slices, and which act in directions perpendicular to the said parallel planes, which are the boundaries of the slices of the bridge, are to be considered as weight only; and such portions of iron as come under neither of these descriptions must be divided by just reasoning, upon the well-known principles of the resolution of forces, and a due consideration of all the circumstances, and then be placed part to one account, and part to the other.

It appears that in regard to an iron bridge of the magnitude of that proposed, not only the weight of the iron made use of, but also its elasticity, and still more its cohesion, are powers which enter into every part of the investigation of the construction. The consideration of these powers presents a very difficult subject, but unless something be settled respecting them, every conclusion that pretends to any thing like precision must be absolutely fallacious. How should the steps in an argument be probable, when the premises are all conjecture? As far as mere weight is concerned, the mathematicians very readily determine curves of equilibration as they are called, and it certainly deserves very seriously to be considered, whether after all it may not be the safest way to dispose of the weight in such proportion as to make all in perfect equilibrio, on the supposition that there was neither cohesion nor elasticity in the materials.

If the natural powers of the iron in regard to its cohesion, elasticity, and strength in general, under all the circumstances in which it may be employed in this occasion, could be ascertained with any tolerable degree of exactness, then it would be undoubtedly the best method to take into consideration all those powers so estimated, and also the gravity of the materials, and reduce the whole to a rigid calculation proceeding upon a sound theory, and to rely upon the conclusion in practice; but if there be too much reason to suspect that the powers above-mentioned cannot be estimated from any known facts, with the requisite degree of probability of being near the truth, then the question will be whether in that case it may not be most prudent to compute merely upon *the weight of the materials and their action as wedges*, considered as the data, and so to determine the curve of equilibration. To a bridge constructed upon the principles last-mentioned, so that the tangential forces should be in perfect equilibrio, and destroy each other at every point of the curve, there might still be superadded all the advantage which a good mechanic can give to it, by making the most skilful use of the powers of cohesion, elasticity, &c. of the metal.

There are, however, two objections to be offered, the first is, that though the above-mentioned powers of cohesion, elasticity, &c., may be allowed to be entirely beyond the reach of computation; when we have in view a structure like this, yet we may still be sure that these powers are very considerable. We may in many cases be quite sure that a power is very great, though we are unable to say how great; and under such circumstances, it is not to be dissembled that no person can foresee whether the effect of a great unknown power may not be to overturn in a great measure the geometrical reasoning itself, respecting the curves of equilibration; or whether, therefore, it might not be better to hazard and compute upon some hypothesis or conjecture, respecting the strength and effect of these powers, rather than to leave them entirely in the dark, and proceed upon the partial consideration of mere weight and wedge action, when we are sure that other powers are actually present. The second objection arises from a considerable practical difficulty which must occur in executing

the work, so that each point of the curve of the bridge shall feel the precise degree of vertical pressure which theory shall assign to it, and unless this difficulty can be got over, all the reasoning concerning curves of equilibration will be of no use. The engineers will be the best judges how far it can be removed, and it will no doubt occur to them, that this matter is much easier to manage in the case of stone bridges.

Dr. Charles Hutton, of the Royal Military Academy at Woolwich, states it as his opinion that all the small frames or parts ought to be so connected together, at least vertically, as that the whole may act as one frame of iron, which can only be destroyed by crushing its parts. For by this means the pressure and strain will be taken off from every particular arch or course of voussoirs, and from every single voussoir or frame, and distributed uniformly throughout the whole mass. Hence it will happen that any particular part which may by chance be damaged or be weaker than the rest will be relieved and prevented from fracture; or if broken, prevented from dropping out and drawing other parts after it which may be next to it, either above or on the sides of it. By this means also the effect of any partial or local pressure, or stroke or shock, whether vertical or horizontal, will be distributed over or among a great number of the adjacent parts, and so break and divert the effect from the immediate places of action. By this means also will be obviated any dangerous effects arising from the continual expansion or contraction of the metal, by the varying temperature of the atmosphere, in consequence of which the bridge will altogether in one mass, in a small and insensible degree, keep perpetually and silently rising and sinking, as the arch lengthens by the expansion, or shortens by the contraction of the metal. This unity of mass will be accomplished by connecting the several courses of arch pieces together vertically, or the lower courses to the next above them, and also by placing the pieces together in such a way as to break joint, after the manner of common or wall masonry, and that, perhaps, in the longitudinal and transverse joints as well as the vertical ones.

Mr. Attwood, of Sloane Street, states that, according to the plan of the bridge, the interior curve is a circular arc, and the whole of the iron-work between the arc and exterior termination on the road is divided into sections of a wedge-like form, the sides of which being prolonged unite in the centre of the circular arch. The sides of the sections considered as plane surfaces, which are projected into the aforesaid lines, are placed contiguous after the manner in which blocks of stone are disposed which form the arches of a stone bridge; but in the plan of the iron bridge, the wedge-like form of the sections, instead of being confined to the arch adjacent to the interior curve, as in the case of stone bridges, is extended throughout the whole structure as far as the road. The ties and fastenings applied to prevent the sections from changing their places in the direction of the sides of the wedges coincide with the lines in which the surfaces of the contiguous sections are united. For these reasons I suppose that the whole iron-work is to be considered as consisting of sections, which act as wedges by their pressure and gravity. It may also be observed, that if the iron-work above the immediate arch be divided by circular arcs or lines of division, drawn from centres situated in the vertical line which bisects the entire arc, the said circular arcs will divide the whole of the iron-works into separate arches, the sections of which may be adjusted so as to form so many distinct arches of equilibration. These arches when united will become a single arch of equilibration.

Colonel Twiss, of Woolwich, states, that every part of a bridge, whether formed in the shape of a wedge, or laid on in horizontal joints, such as the walls and other loading usually erected upon the arches of stone bridges, should be all considered as acting by gravity, and every heavy body so situated, being prevented from falling vertically, will produce a lateral pressure, varying according to circumstances; in considering the strength of arches, I never can suppose the whole to act as one frame, which can only be destroyed by crushing its parts.

Mr. William Jessop, of Newark, says, respecting the practicability of constructing an arch of iron of 600 feet span, and the weight that such a material is capable of sustaining before it will crush with the pressure, I am inclined to believe that those who may critically investigate this matter will remove all doubts on these heads. I can easily conceive that a cube of Portland stone, of 6 inches for instance, would require no great weight to crush it; that such a cube of granite or marble, though much stronger, might also be crushed; but I feel it difficult to form any conception of a weight that would crush such a cube of iron, and though a similar arch of stone would have more surface in contact, yet as its comparative weight (allowing for the difference of specific gravity) would be nearly in proportion to the surface of its section, its advantages on the one hand, of having more points of bearing, will, in my opinion, be much inferior to the advantage, which, on the other hand, will be derived from the greater hardness and tenacity of the materials, and the great decrease of absolute weight.

Presuming then, that there should be no doubt on this part of the subject, it will next be required that all its parts should contribute their due proportion of resistance to the pressure, and that when so constructed, every part should have a disposition to remain at

rest, and that the whole should be so framed, as to be capable of resisting any force tending to alter its form or position, whether from external violence, or from imperfection, or inequality in its parts. Although the parts of the bridge may be so put together as to become one united frame, I should think it right, nevertheless, so to construct the arch, that independent of the framing between the arch and the roadway, it should be equal to the support of the superincumbent weight; and in order that it should be so, it ought to have such a curvature as to counteract the unequal pressure created by the increase of width at the ends of the bridge, or an increased weight on the crown of the arch, or both; it is, therefore, advisable, that instead of the three circular members or segments above the arch, uniting into one on the crown of the arch, and thereby diminishing their weight, each of these segments might be continued distinctly, but resting on or touching each other at the crown; and in the plan also, each rib should be continued independent of the others.

Mr. John Rennie, of Stamford Street, observes that were the arch a semicircle, ellipsis, or other curve, in which some of the frames or voussoirs had but a small inclination to the horizon, the friction arising from the gravity of those frames would be greater than their weight would overcome, and of course would act by pressure only; but in the present case, the arch is so flat, that I apprehend every frame may be considered as a wedge, if its surface were perfectly smooth and straight, and not prevented from sliding by joggles or other contrivances; but as each frame is proposed to be connected by proper joggles or contrivances to the other, and the whole loaded so as to be in equilibrio, except as far as the materials will yield by the weight of the superstructure, I apprehend it may in a great degree be considered as a single frame, which can only be destroyed by crushing its parts.

Mr. John Southern, Engineer, Soho, near Birmingham, observes, that the design represents the parts as one frame; but I do not think it possible to execute it so as to have that effect, nor even that parts can be combined so accurately as to form wedges of so great a length as to reach from the arch to the road; nor do I think it desirable that it should be so constructed; because, as settlement will certainly take place in some degree, when the centres are struck, an immense pressure may possibly be brought on some of the eccentric arches in the spandrills, which are evidently not calculated for such an effect. It is better that the construction should be such as to direct the pressure of force on those parts intended and able to bear it. I therefore consider the lower part only of the bridge, or the arch, constituted by the concentric curves, and which I desire to distinguish by the name of arch, as answering the end of wedges or arch stones; all the superincumbent matter I consider as weight, the pressure of the greatest part of which is, however, increased by the declination from the perpendicular of the members or pillars which point to the centre of the arch, and which communicate to it this pressure. The eccentric members, which form arches in the spandrills, of less curvature than the principal arch, can only be used in keeping the long pillars from bending under the pressure they sustain. Indeed, were the whole pressure of the bridge, by any accident, to come upon any one of these spandrill arches, and were it made strong enough to resist the pressure, the pushing or horizontal force acting against the abutments to overset them, would be increased in proportion to the flatness or radius of the said arch.

The second question propounded by the committee was, whether the strength of the arch is affected, and in what manner, by the proposed increase of its width towards the two abutments, when considered both vertically and horizontally; and if so, what form should the bridge gradually acquire?

Dr. Nevil Maskelyne apprehended that the strength of the bridge would be somewhat increased vertically, and also horizontally, according to the length of the bridge, by the increase of its width towards the extremities or abutments; but that it is increased principally in the direction of its width, so as better to resist the stroke of the mast of a ship going up or down the river.

The Rev. A. Robertson stated that the arch will certainly be affected by increasing the width of the bridge towards the abutments. Such a form will decrease the strength of the arch, to bear the roadway and any weight upon it, and on the other hand it will increase the strength of the bridge to resist any force tending to press it out of the vertical plane. The following are the reasons for this opinion:—If the weights of the several parts be so proportioned, as to give the whole the greatest possible degree of strength, the quantity of matter over any point in the arch must be fixed according to the weight at the crown or at the abutment; it can neither be increased nor diminished, if that law is observed by which a maximum of strength is obtained. If, therefore, the bridge increase in width from the crown to the abutments, the quantity of iron being in an horizontal, it must be decreased in a vertical direction. Consequently, the strength of the bridge will continually diminish in a vertical direction from the crown to the abutments.

Mr. Playfair thought that the proposed increase of width at the extremities, though necessary to steady the bridge in the horizontal direction, and to preserve it in the same vertical plane, is an additional load towards the haunches of the bridge, and tends still more to remove the distribution of the weight from that which the equilibrium requires.

Though there seems to be in the manner of framing, and in the strength of the materials, abundant provision made to supply this want of equilibrium, yet as the tendency of so great an increase of pressure at the haunches must be to make the arch spring at the crown, it may perhaps be expedient to make the wedges near the crown deeper and heavier, in comparison of the rest, than is proposed in the plan. I am aware, at the same time, that the power of the iron bars that compose the framework of the bridge, to resist extension as well as compression, and to draw as well as to thrust (quite different from what happens in stone, where it is the latter only which takes place), may render this precaution unnecessary. Those who have had experience in the construction of arches of iron are the only good judges in this case.

Mr. J. Robeson did not think the mode of widening the bridge towards the ends can be materially improved. This additional width does contribute to increase the load on the haunches, which are already overloaded; but they are so stiff, if united with moderate care, that they are vastly stronger than is necessary, and will not be sensibly affected by this addition. It is in some degree hanging work, that is, hanging by the rest, and not by any regular abutment. This might be given it, as in the *Pont Admirable* between Calais and Ardres, which I examined with great attention many years ago. But this would require a most difficult framing, with oblique angles, each frame and each tie requiring a mould for itself, and it would not be one fiftieth stronger.

Dr. Charles Hutton says, there can be no doubt but the bridge will be greatly strengthened by an increase of its width towards the two extremities or abutments, especially if the courses or parts be connected together in the manner mentioned in the answer to the first question; for thus the extent of the base of the arch at the impost being enlarged, the strength or resistance of the abutment will be increased in a much higher degree than the weight and thrust of the arch, and consequently will resist and support it more firmly. The arch itself will thus also acquire a great increase of strength and stability, both from the quantity and disposition of the materials, as well vertically as horizontally, by which, in the latter direction in particular, the arch will be better enabled to preserve its true vertical position, and to resist the force or shock of any thing striking against it in the horizontal direction; and for the better security in these particulars, considering the immense stretch of the arch, it will be perhaps advisable to enlarge the width in the middle to 50 feet instead of 45 feet, and at the extremities to 100 feet instead of 90 feet, as proposed in the design. As to the form of this width or enlargement, the side of the arch might be bounded by a circular arch or by any curve that will look more graceful, perhaps a very eccentric ellipse will answer as well as any other curve, or better.

Mr. Atwood observed, that the proposed increase of breadth near the abutment does not appear to affect the strength of the bridge in a vertical direction; but a more effectual resistance will be opposed in consequence of this form to any force which may be applied horizontally, and perpendicular to the plane of the arch to alter its position in that direction.

Colonel Twiss stated, that the increasing breadth of the arch at the abutments seems to afford no advantage in the vertical section, on the supposition that no force except gravity could act upon it; but considering the length and breadth, it appears a wise precaution to resist any force acting in a horizontal direction, such as wind, the masts of vessels, &c., and as a guard against vibration; perhaps the strongest form of widening the bridge would be by constructing the sides in straight lines from the centre to the abutments, but the present proposal is cheaper, and may answer the object.

Mr. William Jessop says, that widening the bridge towards the ends will be attended with many inconveniences, and a great extra expense; it is worth consideration whether it may not have sufficient strength to counteract any lateral bias by other means. I am much disposed to believe that if the braces which connect the ribs with each other, instead of being rectangular with the ribs, were to be connected diagonally, so as to form triangles, little more would be wanted to give it the necessary stiffness; but when, in addition to this I consider that the whole covering of the bridge under the roadway may be of iron plates, or reticular gratings with flanches, so that they may be put together with screw bolts and nutts of cast-iron, or with eye bolts and cotters, and form one great iron plate or grating of 45 feet in width; I have no conception of its being capable of any sensible flexibility edgeways; and by diagonal braces, in a vertical as well as horizontal position, which I conceive may be applied without much difficulty, and without the aid of malleable iron. I should have no apprehension of its being liable to any material injury from any external violence, and upon the whole I believe, that an arch of 600 feet span, similar to that in question, with such improvements as it may be susceptible of, is practicable, and capable of being rendered a durable edifice.

Mr. J. Rennie observed, that the strength of the arch will be very much increased horizontally, by the increase of width towards its two extremities. But I do not think any advantage will arise to it vertically from this increase, but rather on the contrary; for, as the additional width will also increase the weight, it cannot be made in equilibrium unless

the iron work is made lighter. Vertical ribs seem the most natural and easy method, and if well braced might probably answer the purpose; but the increase of width towards the extremities is certainly the strongest method of steadying the arch. If the bridge was to be made 50 feet wide at the crown, and 100 feet at the extremities, it would, in my opinion, be sufficient.

Mr. James Watt, of Heathfield, near Birmingham, thought that the width of the roadway of the bridge ought not to be less than 60 feet, including the parapets on each side. In respect to the effects of storms and common accidents, such an arch would be sufficiently stable, without being widened at the ends; but it would be more convenient if it were 90 feet wide at each end, such extra width decreasing gradually, so that, at 150 feet from each end, it should be reduced to the width of 60 feet, from which points the sides would be parallel for 300 feet of the length. It appears to me, that the uprights which stand upon the arch and support the roadway should be perpendicular, as well as the faces of the abutments above the spring of the arch, as the uprights would in that position be stronger. The segments of flat arches in the spandrills, if they acted at all as arches, would have a prejudicial effect, as they would push with great force against the abutments, in points where they were less able to resist than at the spring of the real arch. One reason for enlarging the width of the bridge to 60 feet is, the very great concourse of carriages and passengers, which may be expected in that situation, and which I apprehend would be greater than now cross at either London or Blackfriars Bridge, and surely 60 feet is narrow enough for any principal street in London, as this should be considered.

Mr. John Southern observed, that the pillars that carried the road being radii from the centre, the weight per foot long of the road ought to decrease from the crown, or summit of the bridge, towards the abutments, in order to obtain the equilibrium of the arch; and consequently, instead of increasing in width, the road ought to decrease towards the abutments, supposing it to have the same depth of section. If it keep the same width, or have parallel sides, it ought to get thinner towards the abutments, and still more so if it widen.

By the plan it appears to be twice the width at the abutments that it is at the crown, in which case the thickness at the crown should be, to that at the abutments, nearly as two and two-thirds to one, in order to affect the equilibrium: this is, however, on the supposition that the weight of the arch is of little consideration in comparison with that of the road, by which I mean the sleeper plates, Cornish flags, pavement, &c.

It is hence evident that the road may take any form in the plan, by making its thickness correspond with the weight demanded by the equilibrium; but I must prefer parallel sides, because of the great, if not insuperable difficulty of making them curved; and because I do not perceive that much advantage can be gained towards horizontal stability by that form, which seems, as I conceive, to be the main object; but which may be better attained by diagonal braces.

Mr. William Reynolds, of Colebrooke Dale, says, I have no doubt but the strength of the bridge is very materially affected by the increase of width towards the extremities, and which will operate in a favourable manner in every respect, as it not only strengthens the lateral bearing, but gives a greater abutment to the pressure endways, which will be very advantageous.

Mr. Charles Bage, of Shrewsbury, observed, it was an excellent thought to make the bridge wider at the ends than in the centre, not only for the convenience of the passage over it, but for the opportunity it affords of giving firmness to resist tempests, or any other horizontal pressure.

The third question to be answered was highly important, as it demanded in what proportion should the weight be distributed from the centre to the abutments, to make the arch uniformly strong?

Dr. Nevil Maskelyne apprehended this question to relate to the principle of equilibration. But considering the question to be relative to the strength of cohesion of a perpendicular section of the bridge, as opposed to the stress arising from the weight acting against it to overcome it, it appears to me to make the bridge equally strong from one end to the other; the thickness of the rib frames should be diminished more and more in going from the centre to the extremities of the bridge, and that in the inverse ratio of the square of the height of the perpendicular section above the arch. This it is evident will much diminish the quantity of materials and weight of the bridge, and thereby further strengthen the bridge, and lessen the expense. This subtraction of the materials, however, in going towards the ends, is contrary to what is required for an arch of equilibration, at least of a circular one.

Rev. A. Robertson, previous to answering this third query, stated the following particulars relating to the circle, of which the arch of the bridge would be a part. The diameter is $\frac{18845}{13}$ or $1449\frac{8}{13}$ feet, the circumference 4554·10103763. The length of the arch of the bridge will be 618·59872427 feet, and its magnitude 48° 54′. Having ascertained these

particulars, I proceeded, with a view to answer this third question, to calculate the proportional weight at the extremity of every fifth foot from the crown of the bridge, the weight at the crown being supposed to be one. These are put down in the following table: the first column contains the length of arches in feet from the crown; the second column contains the weights at the extremities of these lengths; the length of arch and the weights at the extremity of that length being in the same line, and adjoining to one another. If therefore it be determined upon that the weight at the crown shall be any number as n, the weight at the extremity of every fifth foot may be obtained by multiplying the number in the second column of the first table by n. As the length of half the arch is 309·299, the last length is not a complete multiple of 5.

If the weight over a portion of the arch at the abutment be given, the weight at the crown may be ascertained. Thus if the weight over a portion of the arch of 10 feet at the abutment be x, the weight x divided by 11·9911 will give the weight at the crown.

1st Col.	2d Col.	1st Col.	2d Col.	1st Col.	2d Col.	1st Col.	2d Col.
5	1·00007	85	1·0209	165	1·0816	245	1·1909
10	1·00027	90	1·0211	170	1·0866	250	1·1997
15	1·00063	95	1·0262	175	1·0923	255	1·2088
20	1·00114	100	1·0290	180	1·0979	260	1·2181
25	1·00178	105	1·0321	185	1·1039	265	1·2277
30	1·00256	110	1·0353	190	1·1099	270	1·2375
35	1·00367	115	1·0386	195	1·1162	275	1·2477
40	1·00458	120	1·0422	200	1·1226	280	1·2582
45	1·00581	125	1·0451	205	1·1293	285	1·2689
50	1·00717	130	1·0497	210	1·1371	290	1·2799
55	1·00870	135	1·0537	215	1·1433	295	1·2913
60	1·01034	140	1·0579	220	1·1507	300	1·3030
65	1·01210	145	1·0623	225	1·1583	305	1·3150
70	1·01410	150	1·0669	230	1·1661	309·299	1·3256
75	1·01620	155	1·0716	235	1·1741		
80	1·01850	160	1·0765	240	1·1824		

From the form of the bridge, and the law by which the weights over the several parts must be regulated, it is evident from the table, that proceeding from the crown to either of the abutments the quantity of metal must be less and less in proportion than the spaces occupied; or, in other words, if I may use the expression, the metal must become more and more rarified. It therefore follows, that proceeding from either abutment to the crown, the metal must become more and more condensed. The limit of condensation at the crown, however, is that of solidity, and therefore a greater weight cannot be laid over a given portion of the arch at the abutment, than that which, regulated according to the established law, will render it necessary to use solid blocks of metal at the crown.

Mr. Playfair replied, that the distribution of the weight, so that these wedge-form frames may be in equilibrio, and may support themselves even if they were not connected but by their mutual pressure, can easily be determined, but will give a construction hardly applicable in practice. The equilibrium of the parts would require that the weights of the wedge, at the spring of the arch, should not exceed the weight of that at the crown, in a greater proportion than that of six to five, and that at all the intermediate points, this difference of one-fifth should diminish, as the square of the distance from the crown diminishes. Thus the crown wedge being of the weight a, the wedge at the abutment should be of the weight $a + \frac{a}{5}$; the first wedge from the crown, $a + \frac{a}{5+31^2}$; the second $a + \frac{4a}{5+31^2}$; the third $a + \frac{9a}{5+31^2}$; and so on for all the other thirty-one frames that compose one-half of the bridge, computing the distance from the crown by the space between the crown and the middle point on the base of each frame. This is obviously so remote from the proposed figure of the bridge, and from any that it can possibly have, that the notion of making the parts balance one another, or support themselves by their weight alone, must be entirely abandoned. It may be abandoned too without any loss to the firmness and stability of the bridge, agreeably to what has been already remarked. The perfect balance of the parts is only necessary, if the frames are unconnected and free to slip on one another; the moment that any connection by diagonal braces or other means is established between them, the principle of equilibrium is in effect departed from, and therefore has never been had recourse to in any instance of an iron bridge hitherto constructed. When therefore it is asserted that the iron bridge over the Thames is not meant to stand on the principle of equilibrium, I do not mean in the slightest degree to object to its construction.

Mr. J. Robeson could not answer this question without considering the manner of acting of every bar almost, to see what are in a state of compression, and what are on the stretch. Did the main ring alone act, and act like masonry, the load on every point of it should be as the cube of a line, drawn from the centre of the arch through the point, till it meet a horizontal line. Thus the weights on *a*, *b*, and *c*, should be as $o\,d^3$, $o\,e^3$, $o\,f^3$, *o* being the centre, and *f d* horizontal. But in a mass of frame-work like this, the equilibration theory is of very little use.

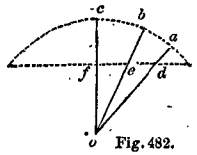


Fig. 482.

Dr. Charles Hutton says, to make the arch uniformly strong throughout, it ought to be made an arch of equilibration, so as to be equally balanced in every part of its extent. When the materials of an arch are uniform and solid, then to find the weight over every part of the curve, so as to put the arch in equilibrio, is the same thing as to find the vertical thickness of the arch in every part, or the height of the extrados, or back of the arch, over every point of the intrados or soffite of the under curves of the arch. In the case of the present design, a strict mathematical precision is not to be expected, or attained by mere calculation on account of the open frame-works of iron in parts of various shapes and sizes. We must, therefore, be content with a near approach to that point of perfection, which can be accomplished in a degree sufficient to answer all the purposes of safety and convenience. Now this can be conveniently done by a comparison of the present design of a bridge with the example of a similar intrados curve in the 4th prop. of my Treatise on Bridges. By that example it appears that the weight above every point on the soffite curve should increase exactly in proportion as the cube of the secant of the number of degrees in the arch, from the centre or middle to the several points in going towards the abutments. This proportion, though it require an infinite weight or thickness at the extremities of a whole semicircle, where the arch rises perpendicular to the horizon; yet for a small part of the circle near the vertex, the necessary increase of weight or thickness towards the extremities is in a degree very consistent with the convenient use and structure of such a bridge, as will be evident by a glance of the figure and curve of that example. For as the whole extent of the soffite arch in the present design is but about 48° 54′ or 24° 27′ on each side from the middle point to the abutments, that is little more than the fourth part of the arch in that example, therefore, by cutting out the fourth part of the arch, it will give us a tolerable idea of the requisite shape of the whole structure, and increase in the thickness when the materials are solid, or at least the increase in weight over every point in the soffite, that is, the figure exhibits a curve for the scale of such increase. Or if we compute the numeral values of the weights or thickness by the rule in that example, in the proportion of the cube of the secants, they will be as in the annexed table, which is computed for every degree in the arch from the middle, supposing the middle thickness or weight to be 10. And the

Degree.	Weight or Height.	Degree.	Weight or Height.	Degree.	Weight or Height.	Degree.	Weight or Height.
0	10·000	7	10·227	14	10·947	21	12·290
1	10·000	8	10·298	15	11·096	22	12·546
2	10·018	9	10·379	16	11·258	23	12·821
3	10·041	10	10·470	17	11·434	24	13·116
4	10·073	11	10·572	18	11·625	24½	13·272
5	10·115	12	10·685	19	11·831		
6	10·166	13	10·810	20	12·052		

true representation of the figure as constructed from these numbers, or the extrados curve determining the true scale of weight or thickness over every such point in the soffite curve, is here exhibited. Here the thickness or height in the middle being supposed 10, the vertical thickness or height of the outer curve above the inner at the extremities is 13·272, or nearly 13¼, and the other intermediate thicknesses at every degree from the vertex are as denoted by the numbers in the latter column of the table. If the thickness at the top be supposed 7, 8, or 12, or any other number instead of 10, all the other numbers must be changed in the same proportion. Now the upper curve in this figure is constructed from these computed tabular numbers, and exhibits an exact scale of the increase of weight or thickness, *so as to make* the whole an arch of equilibration, or of uniform strength throughout when the materials are of uniform shape and weight; and in this case the upper curve does not sensibly differ from a circular arch in any part of it; but as the convenient passage over the bridge requires that the height or thickness at the extremities or imposts should be a great deal more than in proportion to these numbers, denoting the equilibrium of weight, it therefore follows that the frame-work of the pieces above the arch in the filling-up of the flanks ought to be lighter and lighter, or cast of a form more

and more light and open as in the design, so as to bring the loading in those parts as near to the equilibrium weight as the strength and stability of the iron frames will permit.

Mr. J. Rennie observed, that different methods may be adopted of rendering the arch equally strong throughout. It may be balanced by the weight of the frames and loading charged on them towards the extremities, so as to counterbalance that at the crown of the arch, or it may partly be done by weight, and partly by longitudinal braces, placed in such a direction as to answer the same purpose. The latter method will be found very useful in this arch, particularly if put in addition to the weight which forms the equilibrio, for, as I apprehend, it will be impossible to prevent the iron from yielding in some degree; this yielding will be greatest where the depths of the materials are least, which is at the crown of the arch, in which cases the braces will act in opposition to it, with more effect than the simple gravity of whatever load may be placed upon it.

Mr. Attwood stated that the distribution of weight among the sections, so as to form an arch of equilibration, depends on the angles of the sections which form the entire arch. If the angles should be equal, and of the magnitude stated, the weight of each section and the pressure on it appears from calculation to be as set forth in the table which follows. The dimensions of the proposed bridge being

Height of the middle arch - - - -	65 feet.
Span - - - - - - -	600
Radius - - - - - -	724·8
Number of wedges which form the arch	63
Angle of each wedge or section - -	46′ 34″·314.

The inclination of the successive abutments to the vertical line is calculated from the angle of each section, 46′ 34″·314, a degree of exactness not necessary, except to prevent the small errors from accumulating. The angles of the abutments, entered in the second column of the table, are expressed to the nearest minute of a degree. The weight of the highest or middle section, denoted by the letter A, is assumed equal to unity, the weight of all the other sections being in proportion to it.

Sections.	Angular Distances of the Abutments from the Vertical Line.	Weights of the Sections.	Pressure on the Sections next following.	Sums of the Weights of the Sections, deducting the Weight of half the first Section.
A	0·23′	1·000	73·82	·500
B	1·10	1·000	73·83	1·500
C	1·56	1·001	73·86	2·501
D	2·43	1·002	73·90	3·503
E	3·30	1·003	73·95	4·506
F	4·16	1·005	74·02	5·510
G	5·3	1·007	74·10	6·517
H	5·49	1·009	74·20	7·526
I	6·36	1·012	74·31	8·538
K	7·22	1·015	74·43	9·553
L	8·9	1·019	74·57	10·57
M	8·56	1·023	74·72	11·59
N	9·42	1·027	74·89	12·62
O	10·29	1·032	75·07	13·65
P	11·15	1·037	75·26	14·69
Q	12·2	1·043	75·47	15·73
R	12·48	1·049	75·70	16·78
S	13·35	1·055	75·94	17·84
T	14·22	1·062	76·20	18·90
U	15·8	1·069	76·47	19·97
V	15·55	1·077	76·76	21·04
W	16·41	1·086	77·06	22·13
X	17·28	1·094	77·38	23·22
Y	18·14	1·104	77·72	24·33
Z	19·1	1·114	78·08	25·44
A	19·48	1·124	78·45	26·57
B	20·34	1·135	78·84	27·70
C	21·21	1·147	79·25	28·85
D	22·7	1·159	79·68	30·01
E	22·54	1·172	80·13	31·18
F	23·40	1·185	80·60	32·36
G	24·29	1·199	81·09	33·56

Mr. John Southern stated that the weight of a foot long of the road, at any point *a*, ought to be to the weight of the same length at *d*, as the cube of the cosine of the arch *c b* is to the cube of the radius, or as the line *d e* is to the line *d f*, wherein *d* is the centre of the arch *c b*, *b*, the summit or crown, *a b*, a tangent to the curve at *b*, *c e* parallel to *a b*, *a f* at right angles to *d a*, and *c a* and *b f* continuations of the radii *d c* and *d b* respectively. In the case of the proposed bridge, wherein the point *c* at the abutment is about 24½ degrees from *b*, the weight of a foot long of the road, at the abutment to that at the crown, is as three to four nearly.

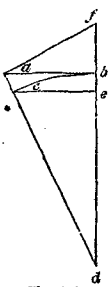


Fig. 483.

As the weight of the arch will not, in fact, be inconsiderable, this difference will not be so great as this rule makes it, but unless the real or the relative weights of the parts of the bridge were given, it is not easy to express the ratio required.

The fourth question demanded, What pressure will each part of the bridge receive, supposing it divided into any given number of equal sections, the weight of the middle section being known; and on what part, and with what force, will the whole act upon the abutments?

Dr. Nevil Maskelyne, upon the supposition that the whole acts as one frame of iron, stated that there would be no horizontal thrust acting on the abutments, and the bridge will rest and press perpendicular to the horizon upon the two abutments, each of which will support half its weight, and if the thickness of the rib frames be made in the proportion mentioned in the answer to the third question, the stress will be alike on every part.

Rev. A. Robertson said, proceeding from the crown to either of the abutments, and supposing half the bridge to be divided into sixty-two sections, each of them, except the last, over a portion of the arch 5 feet in length, the weights of the several sections will be as expressed in the second column of the following table. The first column of the table contains the numbers of the sections of half the bridge, reckoning from the crown. The second column contains the weights of each of the sections, the weight of each section being on the same line with its number. The third column contains the whole weight of 123, &c. sections, reckoning from the crown of the bridge: in this table the weight at the crown is supposed to be 1. If, therefore, any weight be determined upon for the crown, the weight of any section, regulated according to this determination, may be obtained by multiplying the weight so determined upon, by the weight of the same section in the table.

1st Col.	2d Col.	3d Col.	1st Col.	2d Col.	3d Col.	1st Col.	2d Col.	3d Col.
1	4·9969	4·9969	22	5·0120	110·8500	43	5·4374	221·5345
2	5·0009	9·9978	23	5·1228	115·9728	44	5·4791	227·0136
3	5·0022	15·0000	24	5·1342	121·1070	45	5·4990	232·5126
4	5·0031	20·0031	25	5·1459	126·2529	46	5·5311	238·0437
5	5·0052	25·0083	26	5·1585	131·4114	47	5·5524	243·5961
6	5·0075	30·0158	27	5·1713	136·5827	48	5·5743	249·1704
7	5·0105	35·0263	28	5·1847	141·7674	49	5·6047	254·7751
8	5·0150	40·0413	29	5·1987	146·9661	50	5·6319	260·4070
9	5·0164	45·0577	30	5·2134	152·1795	51	5·6600	266·0670
10	5·0220	50·0797	31	5·2247	157·4047	52	5·6887	271·7557
11	5·0231	55·1028	32	5·2437	162·6484	53	5·7182	277·4739
12	5·0324	60·1352	33	5·2604	167·9088	54	5·7484	283·2223
13	5·0375	65·1727	34	5·2652	173·1740	55	5·7797	289·0020
14	5·0439	70·2166	35	5·3067	178·4807	56	5·8114	294·8134
15	5·0509	75·2675	36	5·3127	183·7934	57	5·8399	300·6533
16	5·0580	80·3255	37	5·3314	189·1248	58	5·8778	306·5311
17	5·0656	85·3911	38	5·3504	194·4752	59	5·9120	312·4431
18	5·0740	90·4651	39	5·3704	199·8456	60	5·9400	318·3831
19	5·0827	95·5478	40	5·3909	205·2365	61	5·9908	324·3739
20	5·0937	100·6415	41	5·4082	210·6447	62	5·1764	329·5503
21	5·0965	105·7380	42	5·4524	216·0971			

The pressure against each abutment, in a direction parallel to the horizon, is 724·8, the weight at the crown being 1. If, therefore, a weight be determined upon for the crown, the pressure at each abutment will be found to be 724·8 times this weight. If the weight over a certain portion of the arch adjoining to the abutment be given, the weight at the crown may be found as mentioned above, and the horizontal pressure at the abutment may then be determined. Thus, if the weight of matter over a portion of the arch 10 feet in length, adjoining to the abutment, be 340 tons, the weight at the crown will be 28·354, and the horizontal pressure at each abutment will be 20550·9792 tons. In this

case the weight of half the bridge will be 28·354 x 3295503, which is equal to 9344·0692062 tons; the weight of the whole bridge will therefore be 18688·1384124 tons. As the law which secures a maximum of strength produces an equilibration throughout the whole arch, the horizontal pressure throughout is the same as against the abutment. In adjusting the strength of the abutment to resist the horizontal pressure, the pressure must be supposed to act in the line from which the arch springs.

Mr. Playfair observed, the pressure on the abutments will be found by multiplying half the weight of the bridge by the number 2·41605, or by multiplying the weight of the whole bridge by 1·20802; the pressure on each abutment will therefore exceed the whole weight of the bridge by about $\frac{1}{5}$. This immense pressure must be counteracted by abutments of great size, and of the most solid structure; it would be worth while to compare this pressure with the thrust against the abutments or piers of some well-known stone bridge, such as that of Westminster or Blackfriars; one would be enabled by that means to form some notion of the comparative strength required in the abutments. The rule above laid down gives the pressure in the direction perpendicular to the face of the abutment; of that pressure one part is directed downwards, and may be had by multiplying the foregoing number by ·4139, and hence the perpendicular pressure on the abutment is found nearly equal to the weight of half the bridge.

The other part, that which acts on the abutment horizontally, and which it is of most consequence to know, is found by multiplying the pressure formerly computed, namely, that which is perpendicular to the face of the abutment, by ·91, which brings out the horizontal thrust against the abutment, equal to the whole weight of the bridge multiplied by 1·099, or nearly equal to the whole weight increased by one tenth part.

The horizontal thrust at the crown may be found by multiplying the weight of the bridge by 1·188; I would not, however, have it understood that this last number is accurate, as the investigation of it involves the knowledge of the centre of gravity of the bridge, the exact determination of which would require more data and more time than I am in possession of.

Mr. J. Robeson.— I cannot conceive any physical division of this frame, which will enable me to answer this question; I do not believe it possible to divide it into great wedges, which will abut on each other like so many stones.

Dr. Milner observed, that the construction of the arch of this bridge required the ingenuous and mutual communication of the theorists and the practitioners, for computing the horizontal drift or shoot of the bridge, and its action against the abutments.

Dr. Charles Hutton.— By the equal sections mentioned in the question may be understood either vertical sections of equal weight, or those perpendicular to the curve, of equal weight or of equal length; and whichever of these is intended, their thrust or pressure in direction of the curve may be easily computed, if wanted for the purpose of making experiments on the strength of the frames, to know whether they will bear those pressures, or what degree of pressure they will bear without being crushed to pieces. But as it is evident that the frames next the abutment will suffer the greatest pressure of any, I shall here give a computation of the actual pressure there, which may be sufficient, since, if the frames at the abutments are capable of sustaining that greatest pressure, we may safely conclude that all the others, from thence to the vertex, will be more than capable of sustaining the lesser loads or pressures to which they are subject, and this computation will answer the latter and most essential part of the question, viz. On what part, and with what force, will the whole act on the abutments? Now, from the nature of an arch, it appears that the whole pressure on the abutments will be chiefly on the lower parts of the impost, where the lower frame rests on it, and where we shall, therefore, in our computation, suppose it to act; and in the calculation, the whole weight of the half-arch A O must be supposed united in its centre of gravity N. Then, if a vertical line N M be drawn through the centre of gravity N, by computation, it is found that D M is nearly equal to 160 feet, and consequently M E is equal to 140 feet; also if N O be perpendicular to the impost, or

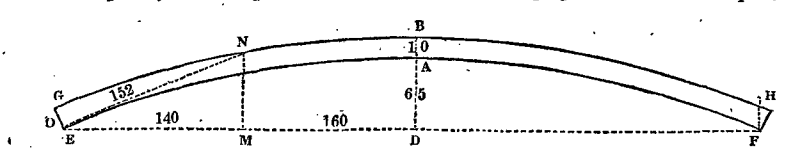


Fig. 484.

in the direction of the arch at O E, we shall have this proportion, viz. as M N (60) is to the weight of half the arch (3250 tons), so is N O (152) to the pressure on the impost in the direction of the arch at O, and so is M E (140) to the horizontal thrust or pressure in the direction M E. This gives 8233 tons for the pressure on the impost at O in the direction

of the arch, and 7583 tons for the horizontal thrust in direction ME, being the pressures at each end of the bridge. We may therefore estimate the greatest pressure on the east, or abutment frame, at about 8000 or 9000 tons.

Mr. Atwood.— The weight of the highest or middle sections being denoted by unity, the proportions of the pressures on all the other sections in respect to unity will be found in the fourth column of the table. If the highest section should weigh 100 tons, it appears from the table that the pressure on the first section, or rather the pressure between the first and second section, will be 7300 tons, and the pressure on each of the abutments will be 8100 tons. It may be added, that according to these dimensions, the weight of each semi-arch will be 3350 tons, and the weight of the entire arch 6700 tons.

The fifth question proposed was, What additional weight will the whole bridge sustain, and what will be the effect of a given weight placed on any of the fore-mentioned sections?

Dr. Nevil Maskelyne stated, that an additional weight laid upon any part of the bridge will be supported by the two abutments, each bearing its share in the inverse ratio of its horizontal distance from the weight. The stress of the weight on the part it lies on is as the weight, and the product of the horizontal distances from the two ends of the base, and its stress upon the centre of the bridge will be to the stress there arising from the pressure of the whole bridge, as the weight laid on is to the whole weight of the bridge.

Let us suppose the additional weight laid upon any part of the bridge to be that of a loaded waggon, which we will suppose to be 7 tons; there is no doubt but that this bridge may easily be made strong enough to support this by the connection of its parts; but as the load might be laid on, so as to press upon the iron plate in the interval between two adjacent ribs, it will be proper to calculate the thickness it may be necessary to give to the plate to sustain such pressure. I find that if the interval of the ribs be 6 feet, a plate of 8 inches thick will be above four times stronger than what would barely support the weight.

Rev. A. Robertson. — The maximum weight which the bridge will sustain depends upon the strength of cast-iron, and, as far as I know, experiments have not been made to ascertain the strength of cast-iron. As far, therefore, as relates to the first part of this query, there are not data sufficient for determining by calculation the weight required.

The effect of a given weight placed over a given point of the arch may be ascertained in the following manner. Let A, B, D, E, F, represent the bridge, and suppose a given weight to be placed upon the point H, in the roadway; let the straight line H, K, be perpendicular to the horizontal line A, F, and meet it in K; then the effect of the weight on H, will be as the rectangle under the parts A K, K F, of the horizontal line. The pressure of a given weight will therefore be greatest when it is over the middle part or crown of the arch.

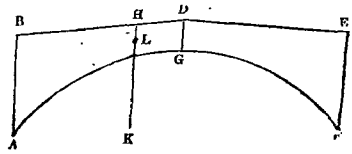


Fig. 485.

Mr. J. Robeson. — The only portion of the arch which can be sensibly affected by an occasional load is the crown, and 40 or 50 feet on each side of it. This is already carrying above 300 tons of roadway; I imagine that any load which can occasionally collect in that portion will be a mere trifle in comparison to this load. We have already seen, that it will increase the mutual compression about $\frac{12}{19}$ of its own weight. If laid on at 180 feet from the crown, this must be increased in the proportion of 2 to 5, because it is supposed to lie on the crown; but I do not think that this increased compression is of any importance. The chief risk is from the vertical strain, and it was for this reason that I recommended diagonal ties, diverging from the lower angle of the middle joint. If a very strong horizontal transverse tie of wrought-iron went across the bridge in this place, ties could be attached to it, and to the underside of the roadway, at considerable distances on each side, which would suspend the intervening portion from parts which have a more extensive vertical connection, and would, in short, make it a more obtuse wedge.

Dr. Charles Hutton. — It is perhaps not possible to pronounce exactly what additional weight the bridge will sustain without breaking, as it depends on so many circumstances, some of which are not known. But considering the great dimensions and strength of the arch-frames and of the whole fabric, we are authorised to conclude, that there is no possible weight which can pass over any part of the bridge, even heavy loaded waggons, whose pressure can be great enough to cause any danger to such strong and massy materials, and especially when it is considered that by connecting all the frames together, by proper bond and otherwise, as mentioned in the answer to the first question, the local additional pressure will soon be distributed through the whole series of the iron framing.

Mr. Atwood. — The sections being adjusted to equilibrium are to be tied or joined together by a method described in a detached drawing; this is intended to prevent any change in the positions of the sections, in consequence of occasional weight which may be brought to press on any part of the arch: any such additional force of weight, if not

opposed, would cause the sections immediately under the additional weight to descend from their places, which cannot happen without the elevation of some other sections, in consequence of which the form of the arch would be altered; but this change is prevented by the fastenings which oppose equally the descent of any section, in consequence of additional weight superincumbent on it, and the ascent of other sections from the excess of pressure caused by the aforesaid superadded weight. But the form of the arch will be preserved entire, notwithstanding the occasional addition of any weight whatever, until the stress on the joinings should be so great as to cause them to give way, or to break or crush the substance of the iron frames which compose the sections. This point of security must therefore depend on the cohesive force of the iron, and affords no data for precise calculation; but the circumstances of the construction afford some grounds for forming a probable conjecture on the subject. The force necessary to cause a change in the positions of the sections depends on the following circumstances:—1. On the massive weight of the sections; 2. on the strength of the joinings, which resists in a certain degree any force applied to separate the sections; 3. the pressure between the surfaces of the contiguous sections, which increases the effectual strength of the ties or fastenings. According to the dimensions stated in the table, the weight of each section is from 100 to 120 tons. And since the sections united by the fastenings are bound or pressed together with a force or pressure from 7300 to 8100 tons, if 30 or 40 tons should be the greatest occasional weight that may probably bear on the same part of the arch, it does not seem probable that the form of the arch would be sensibly changed by the addition of such a weight. 6. The horizontal force, which might be sufficient to press the arch out of the vertical plane, must depend on many circumstances, some of which can be estimated by conjecture only. The principal of these are the following:—

1. The motive force, such as the force of the wind in tempestuous weather, which may be in very high winds at the rate of 8 or 10 pounds on a square foot of surface, when the wind *unfringes* directly against it, according to the experiments of Colonel Beaufoy for ascertaining this point. 2. The magnitude of the areas which may be estimated to be subject to this force of pressure. 3. The angle at which the wind may strike upon it. 4. The effect of any force in pressing the arch out of the vertical plane will be the less in proportion as the massive weight of the iron used in the construction is greater. The strength of the ties or fastenings will also, as in a former instance, add to the stability of the arch, against any force that may press against it.

Mr. John Southern.—An additional weight or force brought upon any part of the arch will distort the curve of equilibration, (an imaginary line, which if the bridge be properly constructed passes through the centre of the frames of the arch,) will render it (the curve of equilibration) prominent opposite the additional force, and will depress it at distant points of the arch; but if these distortions of the imaginary curve keep within the limits of the frames of the arch, no change of position of the parts will ensue, nor will any tension be brought upon the limits of the frames; but if the distortion go beyond the said limits, the joints of the frame will open under the prominent and above the depressed parts of the curve, and the bridge fall, unless those openings be prevented by means which bring on tension in the limbs. The force which will bring on this degree of distortion of the equilibrial curve is in proportion to the weight of the bridge, and nearly the depth of the frame jointly; and I am induced to believe from an experiment I have made, that if the frames be 8 feet deep, the weight which would produce this effect would not be less than 100 feet long of the road.

The Sixth Question.—Supposing the bridge executed in the best manner, what horizontal force will it require, when applied to any particular part, to overturn it or press it out of the vertical position?

Dr. Nevil Maskelyne.—Suppose the largest ship that could strike against it to be of 80 tons, and the bridge to be 7000 tons. The ship then is an eighty-seventh of the bridge; let the ship be going at the rate of 5 miles an hour, or 7·2 feet in a second. This stroke then tends to communicate a velocity of an inch in a second to the whole bridge, if it were free to move. The friction upon the buttresses, or the connection with them, would immediately overcome this motion; but suppose the bridge was free to vibrate upon the middle line of its base as an axis, it would swing to and fro like a pendulum, each vibration taking up about 4 seconds, and as in that time the centre of gravity would not be moved by the velocity acquired by the stroke above 4 inches, it is plain that this small removal from the centre of the base, which is itself 45 feet, can no way endanger the oversetting of the bridge; nor even if it were ten or twenty times greater, but as was said before, the connection with the buttresses will soon bring it to rest.

Rev. A. Robertson.—The power of the bridge to resist any force tending to press it out of the vertical plane will consist of four particulars; the strength of the iron of which it is composed, its width, and the resistance at the abutments, and the inertia of its matters. The absolute effect of the strength of the iron and the width cannot be calculated, for the reasons already mentioned; but, *cæteris paribus*, an increase of width will give the bridge an

increase of power, both at the abutment and in the middle, to resist any force tending to press it out of the vertical plane. In estimating that part of the power which arises from the inertia of matter, we are to suppose the two halves quite unconnected at the middle of the whole, and that each of the halves may be made to revolve about its adjoining abutment in a vertical position, as about an axis. The inertia of each half will then be obtained by multiplying its weight by the square of the distance of its centre of gyration from the abutment.

If the weight of the crown be 1, I find that the inertia of each half of the bridge will be 9245488·995. If the weight over a portion of the arch, of the length of 10 feet, adjoining to either abutment, be 340 tons, the inertia of each half of the bridge will be 262146827·94741 tons.

Mr. J. Robeson.—What force will push the arch out of the vertical plane, the breadth being so considerable in proportion to the length, and the compression at the crown so great? I cannot conceive any force as likely to occur which will put it in any danger. Even the curved form of the sides is favourable to its strength in this particular, for, supposing it pressed from the west side, if the abutments at the east side at the corners do not yield, the whole of the eastern surface, being a concave, must resist as an arch, and although this resistance is not well directed, and allows a twist, it is still considerable. The chief risk is from a ship's mast-head striking the arch near the crown, but the chief risk will be to the ship. The mast-head or rigging, which will then be confusedly bundled about it, may catch, but the ship will be carried through by the current, and may very probably cant round with her broadside to the stream; in this situation, her mast being held fast, she will very likely be heeled down, and take in water and fill.

As, independent of the curved form (horizontally) of the sides, a pressure of one side tends to open the joints on the other; this points out another advantage of the connection by straps, in the manner practised at Wearmouth Bridge.

I cannot form a precise opinion of the effect of these oblique ribs, which appear in the plan, two on each side of the middle rib. They are intended for stiffening the bridge horizontally, but I do not see them in the profile, and must therefore suppose them to range along with the other ribs, so as to be hid by them. I think that their effect would have been twice as great, had they been twice as oblique or gone across from side to side. I observe that they are connected with the cross ties as they go along. If these cross ties which connect the different ribs are of cast-iron, I think that this connection with the oblique tie-ribs exposes them to a great risk of snapping. For the obliquity of these ties occasions the strain of compression to be considerably different, both in magnitude and direction, from the strain of the same kind on the ribs; this difference acts transversely on the cross ties and tends to break them. The underside of the roadway is a very convenient place for diagonal framing, in order to stiffen the bridge horizontally. But whatever is done with this intention must have a very extensive connection with the abutments. The straps to which these braces are attached should embrace a great part of the masonry, that one part may not easily be torn from another.

Dr. Charles Hutton.—This question will be much better answered by means of experiments made on a proper model, than by theoretical calculations *à priori*. But when the bridge is executed in the best manner, with the frames properly bonded and connected together, it seems more likely that any violent shock, such as a ship driving against it, would break any particular frame, rather than overturn such a mass of bonded materials, or even move it sensibly out of the vertical position.

Mr. John Southern.—If the bridge should be considered as a single frame, having strength to keep itself together against a horizontal force applied at the crown, that could under these circumstances overset it; and supposing it free from the top of the abutments, and simply resting upon the end of the arch as feet, this horizontal force applied to the vertex would be more than two-thirds the whole weight of the bridge; but though this supposition of the unity of the parts of the bridge fail us, there is no doubt in my mind of the practicability of making the bridge strong enough, by the application of diagonal braces, to resist any force that can possibly apply to overset it.

The Seventh Question.—Supposing the span of the arch to remain the same, and to spring 10 feet lower, what additional strength would it give to the bridge? or, making the strength the same, what saving may be made in the materials? or if, instead of a circular arch, as in the drawings, the bridge should be made in the form of an elliptical arch, what would be the difference in effect, as to strength, duration, and expense?

Dr. Nevil Maskelyne.—In the proposed bridge of 600 feet in the span and 65 feet high, the radius of the arch is 725 feet, and the length of the arch 618 feet 6 inches; and in the bridge proposed in the question, the height being 75 feet to the same span as before, the radius of the arch will be 637 feet 6 inches, and the length of the arch 625 feet, and the arch more curved by about one-seventh, and consequently stronger by about one-seventh, whether for sustaining its own weight or a weight laid on it. But as it already contains more materials than the bridge of 65 feet height, it does not appear to me to be probable

that a reduction can be made in the materials, so as to make them less than in the other bridge, though it may reduce them to an equality in the two bridges. If an elliptical arch was adopted instead of the circular one, a bridge might be made sufficiently strong, equally durable, more convenient, and with great reduction of expense.

Rev. A. Robertson.—Supposing the span of the arch to remain the same, and the arch to spring 10 feet lower, the crown of the arch would be 75 feet, and the diameter of the circle would be 1275 feet. Let A B D, E B G, be the two arches, whose strength are to be compared, A E, D G being each equal to 10 feet, and perpendicular to the horizon. Take any point H in the arch, A B D, and draw the straight line H K perpendicular to the horizontal line E G, and cutting the arch E B G in F. Then the diameter of the circle of which A B D is a part being $\frac{18845}{13}$ feet, and the diameter of the circle of which E B G is a part being 1275, the strength of the upper arch at H will be to the strength of the under arch at F, as 1275 to $\frac{18845}{13}$, or as 51 to 58 nearly.

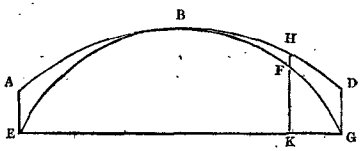


Fig. 486.

The span and height being the same, if the arch consisted of the flat side of an ellipse it would be weaker than the circular arch: if it consisted of the other side of an ellipse, it would be stronger.

Mr. Playfair.—Were the entire elevation of the arch to be 75 feet instead of 65 feet, a considerable addition would be made to the strength of the bridge. The radius of the arch as at present proposed is 725 feet nearly; if the elevation were 75 feet, the span remaining 600, the radius would be shortened to 637 feet 6 inches, and the strength of this latter arch, in as far at least as it depends on the wedge-form figure of the frames, would be to that of the former in the inverse of that proportion, or as 725 to 637, or as 8 to 7 nearly.

In this I suppose the weight and strength of the iron frame-work to remain the same. As more weight would no doubt be required in this second construction than in the first, the real advantage gained would not be so great as has been just stated, or as a seventh part.

As to the elliptic arch, I do not think that any advantage would be obtained by introducing it in the room of the circular. An elliptic arch, indeed, might be so employed as greatly to lessen the horizontal thrust on the abutments, but the curvature at the crown would be rendered so small that the bridge would be greatly weakened at that point, deriving there no advantage from its figure, and depending on the mere strength of the iron.

Mr. J. Robeson.—Making the arch spring 10 feet lower will diminish the thrust on the abutment one-fifth, as also at the crown, and by giving more curvature at the crown will make longer joints. This will greatly strengthen the bridge, but this advantage will be lost by making it elliptical, not from a want of equilibration, because this structure should not be compared with masonry, but for want of long joints near the crown, and an opportunity of using better disposed diagonal braces. Such a degree of ellipticity as will be sensible to the eye and graceful will certainly make the bridge extremely weak in the middle.

Dr. Charles Hutton.—Should the arch spring 10 feet lower than in the design, the bridge would be more stable, because the thrust or pressure on the abutments would be directed lower down, and more into the solid earth, and in general, the lower the springing of the arch, the more firm the abutments and stable the bridge, if the height of the crown above the springing of the bridge be the same. But the greatest advantage would be by making the bridge in the form of an elliptical arch instead of the circular one, in all the articles of strength, duration, convenience, and expense. For, as the elliptical flanks require less filling up than the circular, this will produce a great saving in the iron work, and this same reduction of materials in the flanks towards the abutments is the very cause of greater strength by reducing the weight there, nearer to the case of equilibration, since that very extraordinary mass employed in the flanks of the circular arch destroys the equilibrium of the whole by an overload in that part. The elliptical arch will also be much more convenient, as it will allow of a greater height of navigation way between the water and the soffite of the arch. The elliptical arch is also a much more graceful and beautiful form than the circular arch.

Mr. Atwood.—It does not appear to me that there would be any material difference in the strength and duration of the arch, whether it is constructed in an elliptical or circular form, all the parts being executed equally well in both cases. The expense, it may be pre-

sumed, will principally depend on the quantity of materials used, to be determined by the degree of strength, arising from massive weight, it may be proposed to give to the structure; and the distribution of the mass among the several sections will be regulated according to the principle adopted for establishing the equilibrium, which, it appears to me, will be to all practical purposes the same, whatever be the form of the arch.

Colonel Twiss.— Increasing the rise of the arch 10 feet, and leaving the span the same, would strengthen the bridge, chiefly by increasing the width of the back part of the voussoir; but I cannot state the exact proportion, nor do I believe any theory can; neither do I think that theory can answer the second part of this question, but I am of opinion, that when an arch can be built to answer its object, and yet contain less than sixty degrees, that in all such cases the segment of a circle is to be preferred to an elliptical one.

Mr. John Southern.—The span of the arch remaining the same, as also the weight of the road, the stress or compressing force, which the arch frames would suffer, and also the horizontal push against the abutments, would be lessened, by increasing the altitude, or versed sine of the arch, nearly in the inverse proportion of the altitude, or more accurately, in the present instance, as eight to seven. It would appear, therefore, that the members of the arch might be lessened in section to sustain the same road, but as the road itself is supposed to be the same weight, the whole quantity of materials of the bridge would not be lessened by increasing the altitude of the arch in any such ratio as the above; and the force that would break up the bridge would rather be lessened, supposing the depth of the arch frames the same.

The elliptical arch is better adapted to resist the pressure of a road of uniform thickness, which is supported by pillars, pointing to the centre of the arch, especially if it widen towards the abutments; but for the same altitude, as it implies a less degree of curvature at the crown, it necessarily induces a greater compressing force on the arch frames, which, of course, will be transmitted to the abutments. The degree of ellipticity which the case would demand is, I think, too trifling to afford greater convenience for vessels to pass under; it cannot be more durable, being made of the same materials, but it will certainly be much more expensive and difficult to execute well than the arch of a circle.

Fourteen other questions were submitted to these professors and others by the select committee, but they were chiefly of a nature relating to the material and cost, which were not very satisfactorily answered; and Mr. John Playfair concludes his report by observing, "That it is not from theoretical men that the most valuable information in such a case as the present is to be expected. When a mechanical combination becomes in a certain degree complicated, it baffles the efforts of the geometer, and refuses to submit even to the most approved methods of investigation. This holds good particularly of bridges, when the principles of mechanics, aided by all the resources of the higher geometry, have not yet gone further than to determine the equilibrium of a set of smooth wedges, acting on one another by pressure only, and in such circumstances as, except in a philosophical experiment, can hardly ever be realised. It is, therefore, from men educated in the school of daily practice and experience, and who, to a knowledge of general principles, have added, from the habits of their profession, a certain feeling of the justness or insufficiency of any mechanical contrivance, that the soundest opinions on a matter of this kind can be obtained."

Iron Bridges.— Colebrook Dale, over the Severn, was the first erected in England, and was completed after the designs of Abraham Derby, in the year 1777. It is situated between the villages of Madeley and Brosely in Shropshire, and where the river is both narrow and rapid.

The abutments are of stone, and were built up about 10 feet above the common low water mark; they are finished off with a platform of squared freestone, in breadth 10 feet, which is made to answer both for a base for the springing of the arch and for a towing path.

Cast-iron plates, 4 inches in thickness, formed with sockets to receive the ribs, are laid upon this platform, and to save metal the plates are cast with considerable openings. On these rest the five principal or lower ribs, which form the arch; they are 9 inches by 6¼; above them is a second row, cut off at the top by the horizontal bearing pieces, 6½ by 6 inches; and above these is a third row, 6 inches by 6 inches. Between the ribs are upright standards, 15 inches by 6½ inches, with an open space in the middle, 5¾ inches in breadth. The back standards are 9 inches by 6½ inches, with projections for the braces; the diagonals and horizontal ties are 6 inches by 4 inches, and the cast-iron tie bolts are in diameter 2¼ inches.

The covering plates, which reach quite across the bridge, are 26 feet in length, and 1 inch in thickness.

The great ribs are each cast in two pieces, meet at the keys, and are 70 feet in length, being one-half of the entire circumference of the arch, which has a clear span of 100 feet 6 inches, and a rise of 45 feet.

In the spandrills are introduced rings of cast-iron, and a railing of the same metal runs along each side of the roadway.

The ribs are nearly semicircular; the height from the ordinary low water to the springing plate is about 10 feet, making a total height from low water to the soffite of the arch of 55 feet.

The weight of the whole of the iron work is 378½ tons.

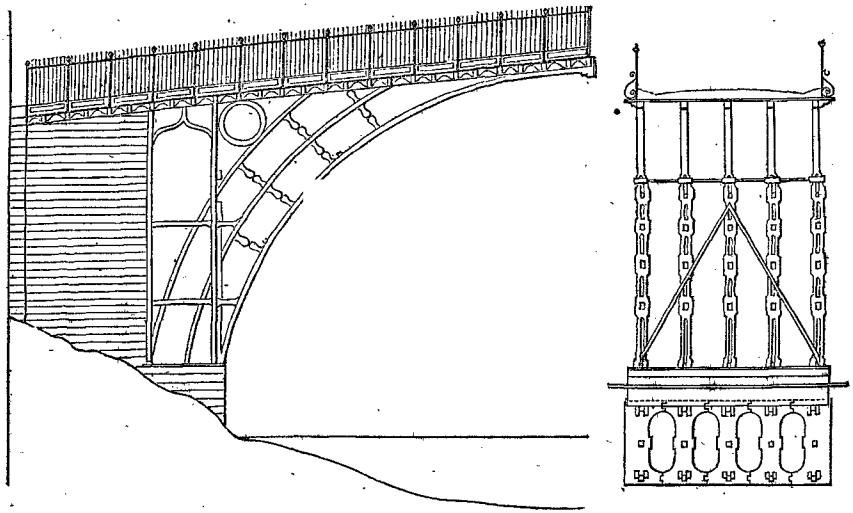


Fig. 487. COLEBROOK DALE BRIDGE.

Behind the iron work, at each extremity of the arch, the abutments are carried up perpendicularly, and the square stone facing backed with rubble work.

Iron Bridge at Buildwas, finished in the year 1796, after the designs of Mr. Telford, is situated about three miles above that at Colebrook Dale. In this example the portion that sustains the road is, as it were, suspended from two large ribs, placed on each side of the

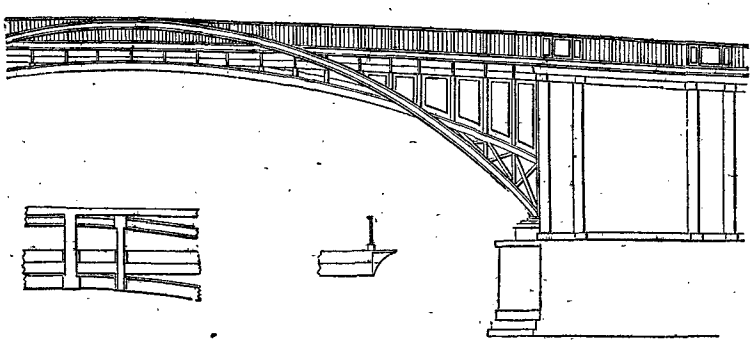


Fig. 488. BUILDWAS BRIDGE.

bridge; the span of the arch is 130 feet, and the versed sine of the ribs, which bear the covering plates, is 17 feet; the breadth across the soffites is 18 feet, and the height from the ordinary low water to the soffite is 30 feet.

This novel mode of construction, which allows the roadway to be kept low, on the suspending principle, was perhaps the first adopted in this country. The bearing-ribs have a curve of one-eighth of their span, or 17 in 130; they rise about one-fourth of their span, or 34 feet, and are maintained securely, both by horizontal ties and cast-iron braces. The whole is covered with 46 plates of iron, 1 inch in thickness, each 18 feet in length; they

are cast with flanches at the sides, 4 inches in depth, and are screwed together, and, being laid according to the curvature of the ribs, and secured firmly at the abutments, form an arch in themselves, and thus in some degree relieve the ribs of the weight they would otherwise sustain. As there is only one rib in the middle of the bridge, others are placed

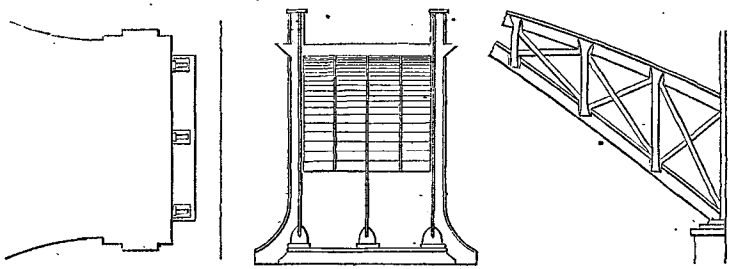


Fig. 489. BUILDWAS BRIDGE.

at right angles, 4 inches in depth, cast with flanches, which serve to support the 18 feet plates that extend across. The suspending ribs are 18 inches in depth, and, exclusive of the moulding, $2\frac{3}{8}$ inches in thickness. The bearing ribs are 15 inches in depth, and $2\frac{1}{2}$ inches in thickness, and each is cast in three pieces, of about 50 feet; the braces are 6 by 3 inches. The principal king-posts are $10\frac{1}{4}$ by $4\frac{1}{4}$ inches. The springing plates are 3 feet broad, and 3 inches thick, cast with openings to save metal. The uprights against the abutments are $4\frac{1}{2}$ inches square. The strongest uprights in the railing are 3 inches square, and those between them 1 inch; they are placed 6 inches from centre to centre, and their height above the road is 4 feet 9 inches.

In each spandrill are three circular arches, formed with hard bricks, which are concealed by a covering of iron plates, an inch in thickness. The abutments are carefully built of squared masonry, filled in with rubble; the foundations are laid upon the solid rock.

The whole weight of iron is $173\frac{1}{2}$ tons, and the cost was about 6000*l.*, including the abutments, the masonry of the wing-walls, (which have a curve both on the plan and vertically,) and the towing path, which is about 10 feet above the level of low water.

Sunderland Iron Bridge, over the Wear, was formed in part out of another contrived by the celebrated Thomas Payne, which was put up at the Yorkshire Stingo, Lisson Grove, and afterwards carried back to Rotheram; it was opened to the public in the year 1796, and was cast at Rotheram, under the superintendence of Mr. Thomas Wilson. It is composed of one arch, the segment of a circle, the chord line being 236 feet, and the versed sine 34 feet; the height from the surface of the ordinary low water to the soffite of the arch is 100 feet, the springing line is 60 feet above the level of low water, the width of the roadway is 32 feet,

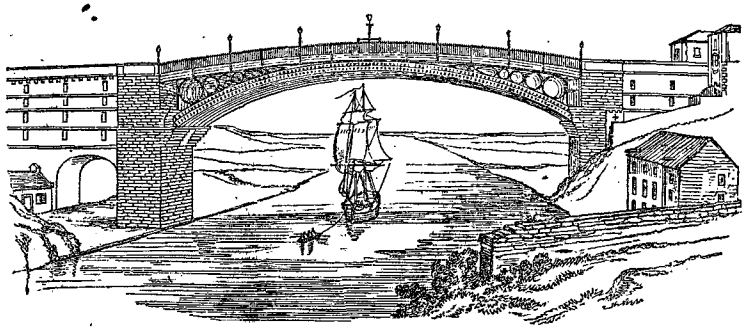


Fig. 490. SUNDERLAND BRIDGE.

and the whole is carried upon six ribs, each composed of 125 small frames, about 2 feet in length and 5 feet in depth, in the direction of the radius. In each of these frames are three pieces 4 inches square, following the curve of the arch, and connected, in the direction of the radius, by two other pieces 4 by 3 inches. In each side of the larger pieces is a groove $\frac{3}{4}$ inch in depth and 3 inches broad, in the middle of which is a hole opposite each cross-piece.

After the abutments were built, and a timber scaffolding constructed across the Wear, six of the frames were placed on the abutments, in the manner of voussoirs, and wrought-iron bars were fitted into the grooves, so as to hold several of them together. Hollow pipes of cast-iron, 4 inches in diameter, fitted to reach between each two frames, were introduced entirely across the soffite; upon the ends of these pipes were flanches, having holes drilled into them to answer to those in the 4-inch pieces of the frames, as well as to those of the

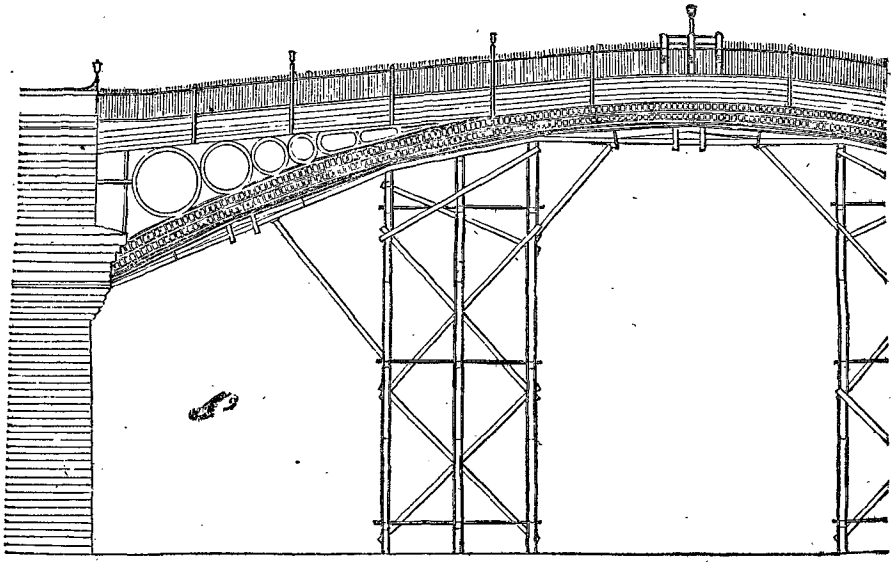


Fig. 491. SUNDERLAND BRIDGE.

wrought-iron bars; through these holes wrought-iron bolts were passed, which brought all the parts together by means of forelocks. The frames do not meet at the upright pieces, but only on the three points of the 4-inch pieces; at the ends of the hollow pipes are small projecting pieces, embracing both the upper and lower edge of the frames, which oppose each other. When the whole of the frames were placed upon the centre, and the arch keyed, in the manner of a stone bridge, the upright pillars were fixed; between them were

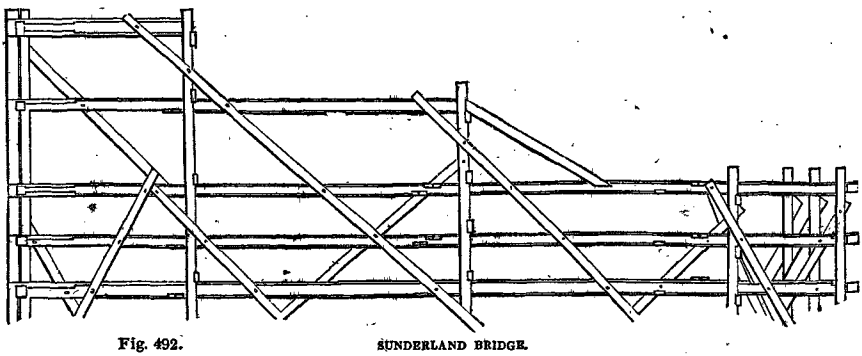


Fig. 492. SUNDERLAND BRIDGE.

cast-iron circles, resting upon the extrados of the voussoirs. The road is carried upon a timber platform, and the railing is of cast-iron.

This magnificent bridge, from its elevation and lightness of construction, is perhaps the boldest attempt that had hitherto been made to cross a river, and at once proved what could be accomplished by the aid of cast-iron; some objections have been made to the number of joints in the main ribs, which might possibly have been lessened, and considerable

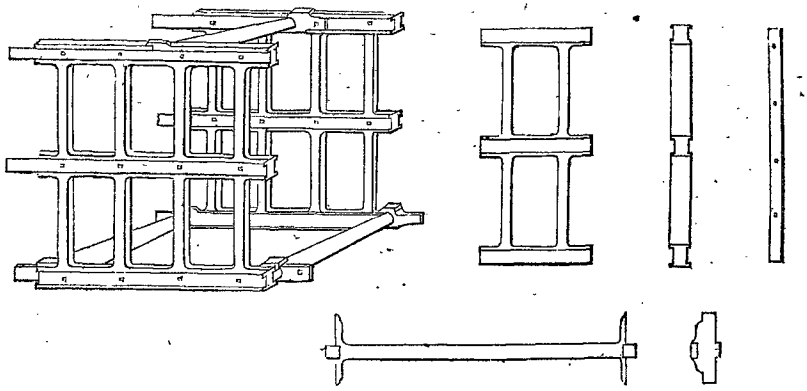


Fig. 493. VOUSSOIRS OF SUNDERLAND BRIDGE.

expense saved in the braces, ties, and bolts; the circles placed in the spandrills are also ill-adapted to support the roadway, the pressure they receive being unequal.

Iron Bridge over the Witham, at Boston in Lincolnshire, executed from the designs of Mr. Rennie, has one arch, with a span of 85 feet, and a rise of 5 feet 6 inches; its breadth is 36 feet. It is composed of eight ribs, each consisting of eleven frames, of a depth, in the direction of the radius, of 3 feet. At the joints cast-iron gratings are introduced across the arch which connect the frames together, in a similar way to those practised in the aqueduct at Pontcysyte. In the direction of the curves are two pieces of iron 7 by 4½ inches, and these are connected in each frame in the direction of the radius by pieces 4 by 3 inches. Upon the back of the ribs pillars 4 by 3 inches are perpendicularly placed to support the roadway. The rise of the arch is only one-fifteenth of its span; the frames are nearly four times the length of those at Sunderland, and being connected with cast-iron gratings instead of wrought-iron is a decided improvement; but the pieces in the frames, which are in the direction of the radius, are perhaps not sufficiently strong, in proportion to the main pieces in the direction of the curve.

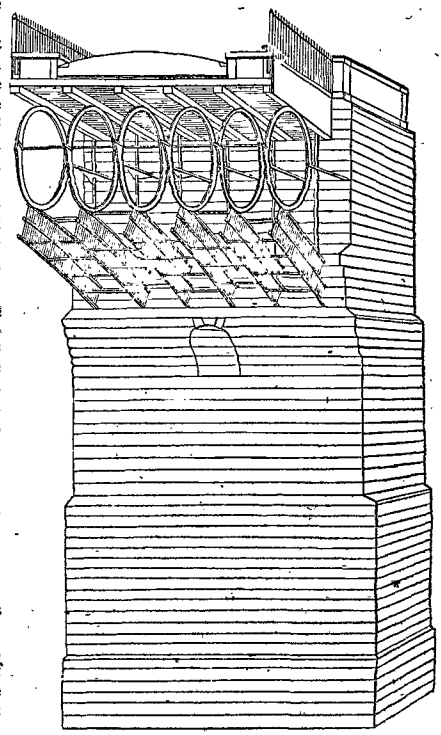


Fig. 494. SECTION THROUGH SUNDERLAND BRIDGE.

Two Cast-iron Bridges over the Avon, at Bristol, built after the designs of Mr. Jessop, each consisting of a single arch of 100 feet span; the rise 12 feet 6 inches, or one-eighth, the breadth 30 feet. There are six ribs, each composed of two pieces, meeting in the middle, and connected crosswise by nine cast-iron ties, dovetailed and wedged into the ribs, their cross sections being T-shaped. The abutments that receive the ribs are laid in courses following the direction of the radius, and on them are plates 32 feet in length, 2 feet 4 inches in breadth, and 4 inches in thickness; each plate has five apertures 5 feet long, and 20 inches in width. The ribs in the direction of the radius are 28 inches in depth and 2 inches in thickness, and have each 80 apertures

12 inches square, separated by bars 3 inches broad, excepting opposite the cross-ties, where the solid metal is 12 inches in breadth. In the middle, where the ribs meet, are flanches 2 inches thick and 8 inches broad, which are connected by 3-inch cast-iron screw bolts. Between the ribs and the bearers of the roadway are perpendicular supports, the horizontal section of which is T-shaped. The road is carried upon cast-iron plates, and protected by railing of the same metal.

Iron Bridge over an Arm of the Sea at Bonar, in the county of Sutherland, in Scotland, under the direction of Mr. Telford, consists of one arch 150 feet span, and rises 20 feet; it is 16 feet in width, and has four ribs. The springing plates are laid in the direction of the abutments, and are 16 feet in length, 3 feet in breadth, and 4 inches in thickness; they are all cast with sockets and shoulder pieces to receive the ribs; in each plate are three apertures, 3 feet in length and 18 inches in width. Each rib is composed of five pieces, 3 feet in depth in the direction of the radius, and $2\frac{1}{2}$ inches in thickness. In the ribs are triangular apertures formed by the pieces in the direction of the radius, and the St. Andrew's cross or diagonals between them, but all parts are of equal dimensions. Where the ribs join a cast-iron grating passes across the whole arch, upon which are cast joggles to receive the ends of the ribs, which are flanched and fixed in the gratings with cast-iron screw bolts. The ribs are preserved in their vertical position by covering the whole with grated flanched plates, secured together and to the top of the ribs by cast-iron screws and pins. The spandrills are filled in with lozenge-work, each triangular form being cast in one frame, with a joggle above and below, which pass into the sockets formed in the top of the ribs, and in the bearers of the roadway. Where these lozenges meet in the middle of their height each has a cast-iron tie, which passes by a notch from each side, and meets in the middle of the breadth of the arch, where they are secured by forelocks. Towards the abutments the lozenges are halved, in order to suit the inclined surface. The covering plates are cast in a reticulated form, the holes or apertures being larger on the under surface than the upper, the better to support the materials of the roadway.

From the experiments made by Dulong and Petit it seems that the temperature of iron is nearly equable, between 32° and 212°; the rate of expansion increasing with the temperature: it is therefore most important that due allowance should be made for the metal's expansion and contraction wherever it is introduced. The arches of the Southwark Bridge are said to rise and fall an inch within the range of our atmospheric temperature: in most of the first constructed French bridges, sufficient attention was not paid to this quality of the metal, and hence the cause of many of the failures where it was employed.

In the construction of an iron bridge it is highly important that the distinction between ties and struts should be well understood; and that cast should not be made use of, where wrought-iron alone can be efficient. M. Duleau, who made several experiments on the malleable iron of Perigord, found that its elasticity was greatly affected by the various weights to which he subjected it, and that there was a point at which it would not again recover its form; and he concluded that a bar of wrought-iron might be safely strained until the extension, at the point of the greatest strain, is equal to $\frac{1}{3333}$ of its original length, without losing its elasticity, and that the load upon a square inch which produces this extension is 8540 pounds. In some of his experiments, however, he found the extension was three times this without permanent loss of elasticity; and thus has the art of construction in iron been latterly directed by the French engineers, who have consequently been very successful. Navier, Rondelet, and others, have calculated the resistance of iron to compression and tension, and upon their data the use of iron is applied. The greatest load they found a bar of malleable iron whose length was 11·8 feet and scantling 1·21 inches square would bear without doubling was 4400 pounds; and upon these results their iron-bridge-builders proceed in proportioning their metal.

Southwark Iron Bridge, over the Thames, at London, was commenced after the designs of Mr. Rennie on the 23d of September, 1814, and completed in April, 1819. The whole was cast at the iron works at Rotheram, in Yorkshire, and weighed 5780 tons; the expenses, amounting to about 800,000*l.*, were defrayed by a joint-stock company.

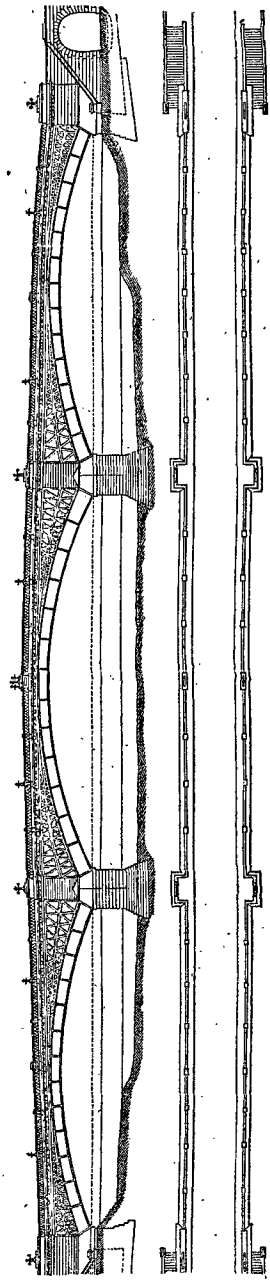
There are three arches, the middle one spans 240 feet, and has a rise of 24 feet; it is composed of eight ribs strongly secured by diagonal braces, each in the direction of the radius, being 6 feet in depth at the top of the arch, and gradually increasing to 8 feet where it rests upon the abutments. The two other arches each span 210 feet. The masonry of the abutments is constructed of stone from Bramley Fall and Whitby; a vertical bond was adopted, running through every two courses at intervals; the masonry of the piers was carried up in the same manner, with horizontal and vertical courses to the springing of the arches, where they radiated to receive the iron-work. The piers are 24 feet in breadth, 56 feet 6 inches in length, and 60 feet high from the bed of the river to the top of the parapet; the length of the starlings is 74 feet 6 inches. The middle arch settled at the vertex after the centre was struck $1\frac{7}{8}$ inches; the entire width of the soffite is 44 feet 4 inches. The foundations of the piers are laid 10 feet below the actual bed of the

river; they are 36 feet in width at the base, and 24 feet at the point where the vertical part of the piers commences; the whole rests upon ten rows of piles.

At high tides the lowest course of masonry is 36 feet below the surface of the water; considerable care was consequently requisite in the construction of the cofferdam. It was formed of three rows of piles representing on the plan three oblong octagons, one within the other; the clear-width of that on the inside was 60 feet, and the length nearly double; the thickness was about 6 feet. The piles were 13 or 14 inches square, and 50 feet in length; of this 15 feet 8 inches were driven into the bed of the river, 28 feet allowed for high tides, and 6 feet above high water. Traverses were fixed inside the dam 60 feet in length, pressing at each end against longitudinal timbers, which prevented the rows of piles from being forced in by the pressure of the water from without. On the inside of the dam, around the space left for the pier, a range of planks was driven, 6 or 8 inches in width, united closely together without either nails or grooves, in order to prevent the ground being washed away between the piles. The piles of the abutments were driven 3 feet 4 inches distant from each other, and covered with a strong frame of timber planked all over. Below were sixteen or eighteen isolated piles, to protect the dams against the craft navigating the river in the service of the works. The first piles were driven to form the figure of the three octagons, and others were then forced into the intervals, so as to close them, and when the three rows were thus completed, the gravelly earth to form the dam was thrown in. A steam-engine of fourteen horse-power, erected on the banks of the river, gave motion to the several pumps, and by means of scaffolding reaching from the shore to the cofferdams the alternate movements were transmitted.

To build the abutments a dam was constructed in front of them, and when the water was pumped out the ground was prepared, at a slope of two in fifteen towards the bed of the river; the piles were then driven perpendicular to this inclination. A timber floor rested on the head of these piles, like that of the piers, and on this was laid the first course of Portland stone, each course being on a plane more and more inclined towards the river; the stones were prevented from sliding by dice and the power of their own weight; by this means the plane of the upper course was made exactly perpendicular to the springing of the arch, and capable of more effectually resisting the pressure of the first rib. The total width of each abutment is 80 feet.

Each arch is composed of eight ribs of the same form and dimension; each rib is divided into two parts; that which forms the lowest contour of the arch is massive, and the other, which rests upon it, consists of open work. These iron voussoirs are in thickness $2\frac{3}{4}$ inches, but additional strength is given to them by a rim of 4 inches in width, which enables the joints to bear greater vertical pressure. Transverse plates of iron of the same breadth and thickness as the voussoirs, and isolating them from each other, traverse all the ribs at right angles, in numbers equal to the joints between the voussoirs of each rib; and on the abutments, where the lowest voussoirs rest, are similar plates to carry the arch. Thus the whole becomes a centre to support first the spandrills, and afterwards the roadway. The spandrills are formed of open work resting vertically upon the voussoirs, and those on the outside have a lozenge



SOUTHWARK BRIDGE.

Fig. 495.

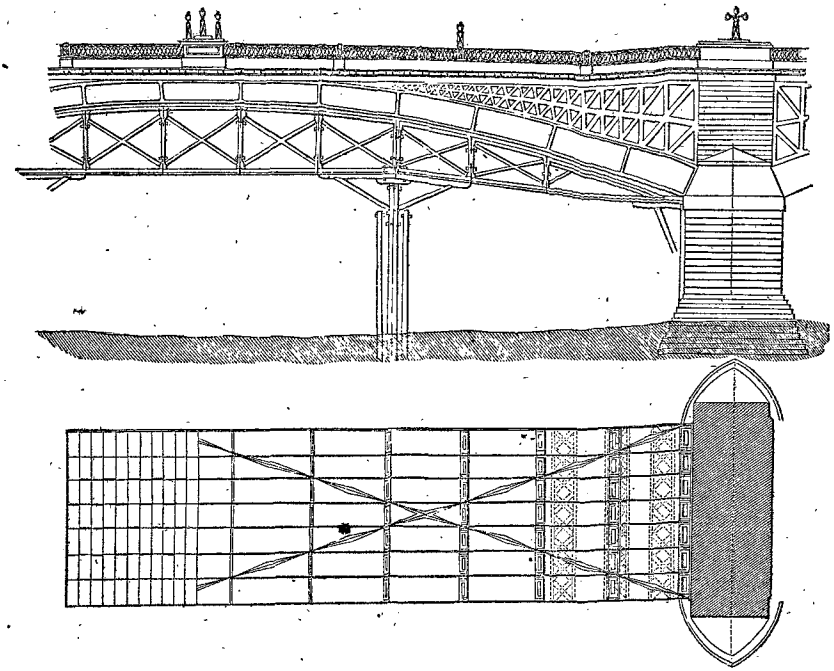


Fig. 496. PLAN AND ELEVATION OF ARCH.

figure introduced between them, diminishing in size as they approach the summit of the arch; these lozenges are contiguous to each other, and united at the extremities of

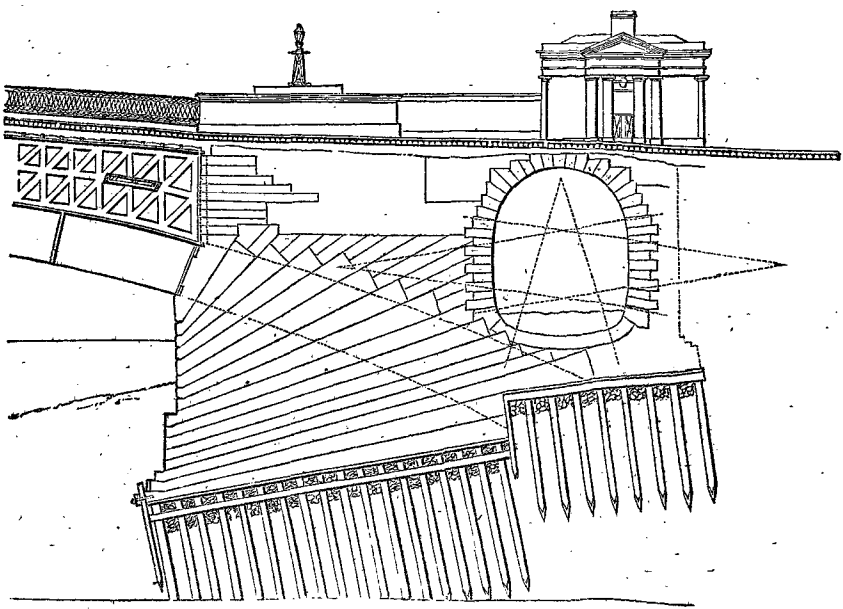


Fig. 497. ABUTMENT AND SPRINGING OF ARCH.

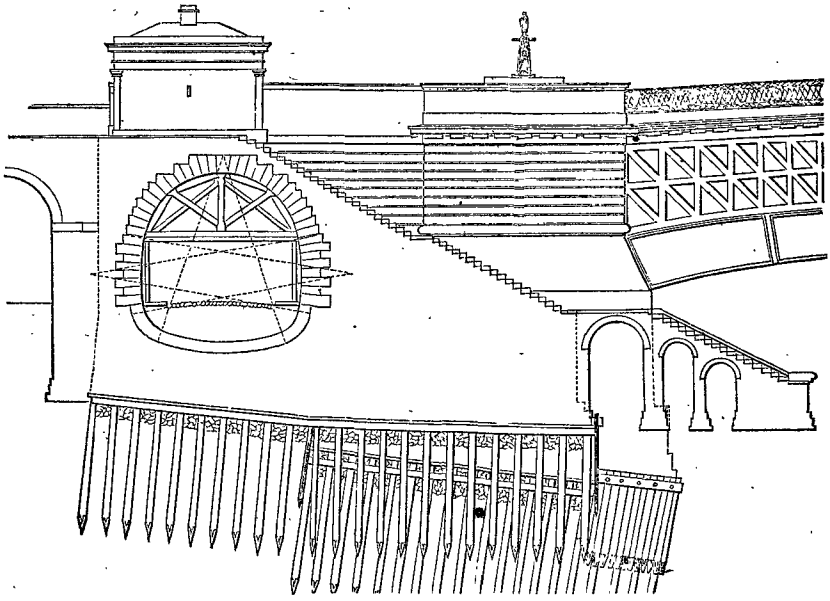


Fig. 498. ABUTMENT AND SPRINGING OF ARCH.

their smaller diagonals, which form a part of a polygon, or rather a segment of a circle, and divide the space comprised between the centre and the platform into two equal portions.

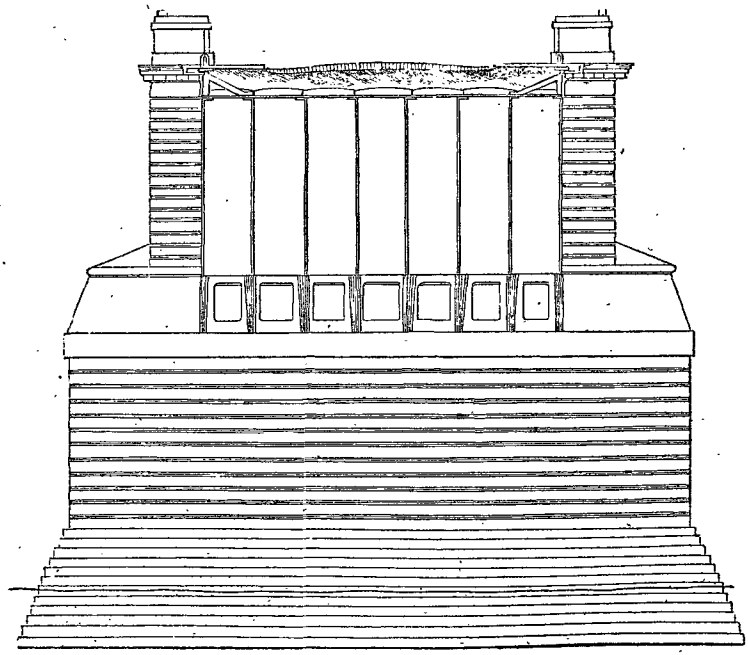


Fig. 499. SECTION THROUGH BRIDGE.

As the lozenges diminish in size, the iron-work of which they are formed is also relatively lessened in dimension; the lower points of the lozenges rest upon the centre, the upper

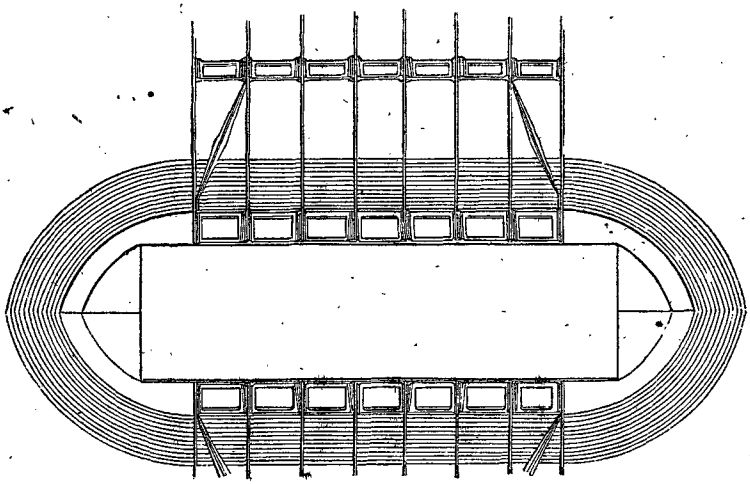


Fig. 500. PLAN OF PIER.

support the bridge road. The vertical sides which compose the ribs are united with screw bolts, passing through the rims raised on the outside, which are occasionally increased in

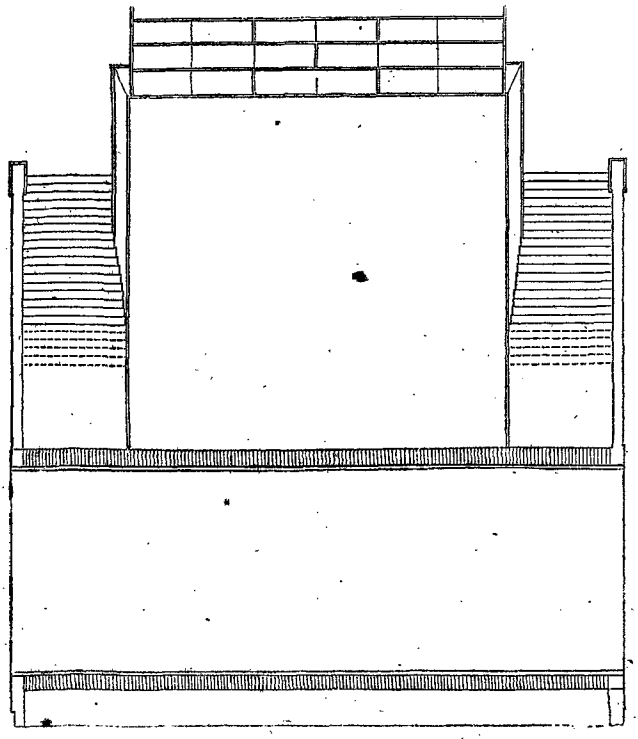


Fig. 501. PLAN SHOWING STAIRS.

thickness. There are two lozenges and four half lozenges cast in one piece; that portion next the abutment has one complete lozenge and two halves. The lower parts of the

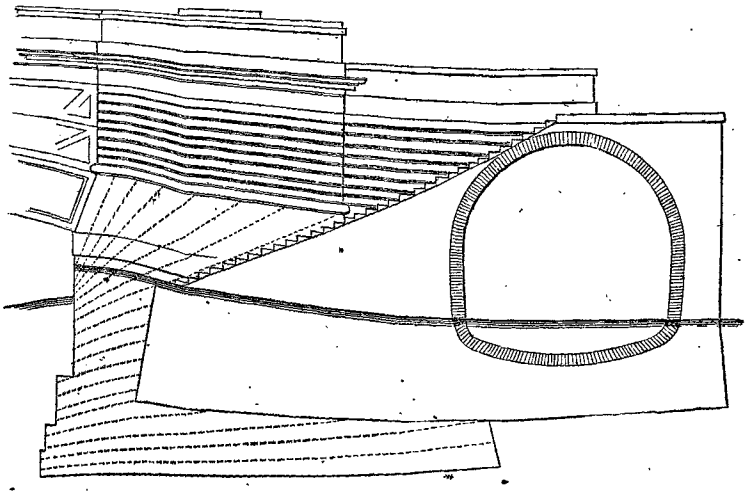


Fig. 502.

FOUNDATION COURSES.

lozenges are connected together by an arch on the extrados of the voussoirs, and the upper portions are united in a similar manner; the entire space between the road and the voussoirs is divided into four distinct series of triangles. That part of the ribs upon which the first series rests has a number of grooves made in the extrados of the voussoirs to receive them, and they are secured by iron bolts passing through the bases and the voussoirs.

Weight of the Materials of Half the Middle Arch.

	Voussoirs.		Diagonals.		Transverse.		St. Andrew's Cross.		Lozenges.		Total.	
	Tons	*Cwts*	*Tons*	*Cwts.*	*Tons*	*Cwts.*	*Tons*	*Cwts.*	*Tons*	*Cwts.*	*Tons*	*Cwts.*
No. 1	62	18	6	11	11	0	9	10	26	4	112	3
2	60	9	2	12	10	13	8	15	20	3	102	12
3	54	15	2	13	10	2	8	2	32	16	108	8
4	51	3	2	11	9	17	-	-	24	5	87	16
5	50	17	2	18	9	15	-	-	32	14	95	19
6	51	2	2	13	9	15	-	-	24	15	88	5
7	25	12	2	12	-	-	-	-	20	7	48	11
											643	14

	Tons	Cwts.
Plates that cover the bridge under the road	152	0
Cornices and railing	77	3
Road and pavement	650	0
Plates resting on the piers and abutments	13	0
Total weight of iron in the three arches	5,584	0
Weight of a half pier	11,000	0

The price of casting, transport, and fixing, was 18*l.* per ton.

Of Mr. Telford's iron bridges, that over the river Spey at Craig-Ellachie consists of one arch of 150 feet span, with a rise of 20 feet. Subsidiary to this main arch, but at some distance from it, are three others, built of stone, 15 feet span each, under the eastern end of approach; the total water-way is 195 feet. This bridge is beautifully situated about 12 miles above Fochabers, where the Spey, rushing among lofty rocks, has cut a deep passage for its waters, and the slender arch, amidst the birch trees and native firs, renders this spot truly interesting; the total cost of the bridge and its approaches, including the rock-blasting on the east side of the river, was not more than 8200*l.*

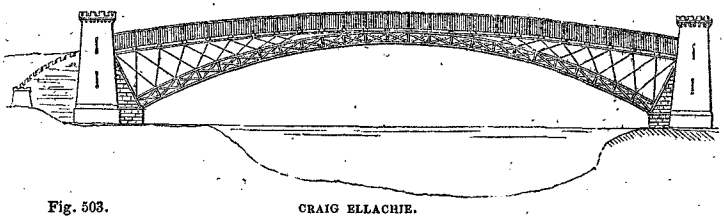


Fig. 503. CRAIG ELLACHIE.

Tewkesbury Bridge, of one arch of cast-iron, was constructed by Mr. Telford over the Severn, at about ½ a mile above its confluence with the Avon; the bed of the river was found by boring to consist of alluvial matter to a great depth.

The masonry of the abutments was laid 6 feet under low water level, upon strong wooden platforms, surrounded by sheet piling about 10 feet in depth; it was carried up to 16 feet above low water, which, allowing 3 feet of masonry to receive the cast-iron springing plates, determined the lower edge of the large ribs to be 13 feet above low water level, the water, in the time of floods, never rising more than 18 feet.

The span of the arch is 170 feet, and its rise about one-tenth of the span, or 17 feet; the breadth, measured across the soffite, is 27 feet; it consists of six main ribs, each 3 feet deep, the thickness of the two outer ones being 2½ inches, and that of the four interior 2 inches. They were all cast in lengths of 22 feet, and are connected at each joint by grated cross-plates, 3 feet in depth, and 2 inches in thickness, to which they are severally screwed.

The whole of the ribs thus united in one arch are placed upon springing plates 3 feet in breadth, and 4 inches in thickness, embedded in the stone abutments; their upper edges are covered with grated plates 1 inch in thickness, and upon the six ribs is a perpendicular lozenge framing to support the roadway bearers, which are connected by wrought-iron rods or cross ties, 1½ inches in diameter, passing through cast-iron tubes with flanches adjusted to the lozenge frames, and retaining them in a perpendicular position, while the wrought-iron bolts, being screwed to the outer ribs of the bridge, prevent them from bending outwards, and the interior of the spandrills are further secured by diagonal braces. The roadway bearers support plates 4 feet 6 inches in breadth, and 1 inch in thickness, with flanches 4 inches in depth at each juncture, by which they are screwed together. Upon the road plates are skirtings to retain the gravel of the footpaths, which are also adapted to receive the bars of the side railing.

The whole is cast from No. 2 Shropshire iron of the best quality, and the work was completed in April, 1826. The cost of the iron-work was 4500*l.*, and that of the masonry, embanked approaches, and land arches, 10,000*l.*

Manchester and Birmingham Railway.—At Fairfield Street is a bridge whose span in a straight line is 128 feet 9 inches, with a versed sine of 12 feet; the width, measured from face to face, is 31 feet.

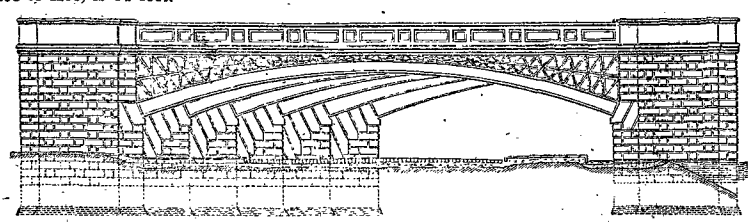


Fig. 504. FAIRFIELD STREET BRIDGE.

Six ribs of iron abut on as many independent walls, each of which are 5 feet 10½ inches thick, and project before each other 12 feet 11 inches. The transverse sections show the construction of the piers, the faces of which are rusticated; an ornamental stone parapet and cornice crown this viaduct, and present a novel and agreeable character.

This bridge, executed after the designs of Mr. George Watson Buck, is remarkable for its acute angle, which is about 24¼ degrees. The weight of the iron work employed in the six ribs was 540 tons, and the whole was admirably screwed together; the remainder of the viaduct is formed with brick arches of 45 feet span. Iron ribs have enabled the engineer to cross rivers and roads in situations where arches of masonry or brick could not have been introduced: in the present instance, the level of the viaduct would not have permitted a rise sufficient; but wherever they can be introduced, there is no doubt that a considerable portion of the expense of iron structures would be saved. For oblique bridges iron constructions are particularly well adapted, and, as in this instance, beautiful in their effect; timber has been employed, as we shall hereafter see, for the same pur-

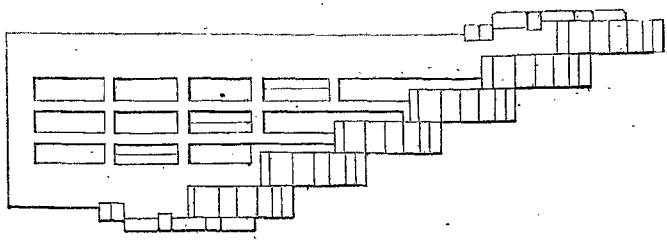


Fig. 505. PLAN OF PIER.

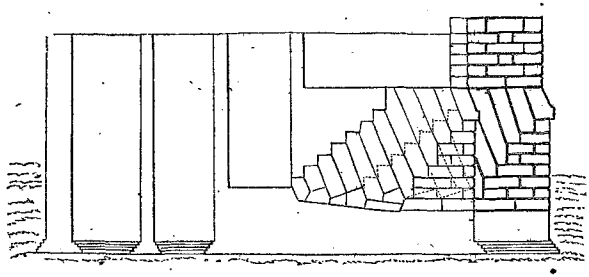


Fig. 506. SECTION OF PIER.

pose, where greater economy was necessary. The masonry of the abutments was well executed, and great care taken to allow for the expansion and contraction of the iron,

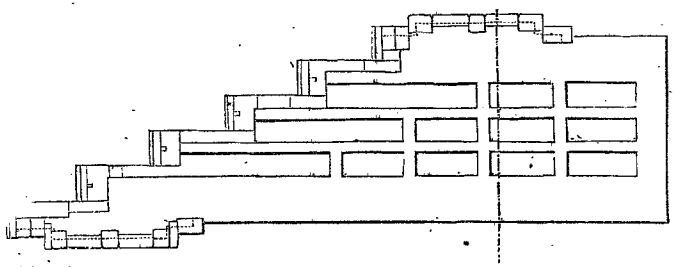


Fig. 507. PLAN.

which was found considerable; it is even reported that the heat of the sun affected the length of some of the outer ribs, during the progress of hoisting them to their situation: and that the dimensions of one, taken by the workmen when on the ground, was increased so much, that it would not answer the position for which it was designed until its temperature had been lowered. One of the first considerations of the engineer, when he employs iron for construction, should be its properties of increasing and diminishing; and he should always provide a means by which the metal can accommodate itself, without thrusting out the works on which it rests or may be in contact.

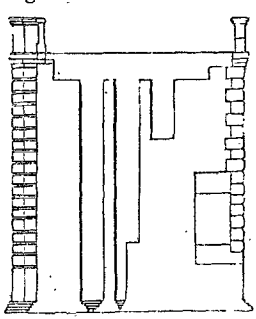


Fig. 508. SECTION.

At the Kildare Canal, in Ireland, the first skew bridges were introduced by Mr. Chapmán, in the year 1787; before that time their advantages do not appear to have been much noticed in England. One executed by that engineer at Finlay Bridge, near the town of Naas, in Ireland, deviated 51 degrees from a rectangle with the canal, and formed an acute angle of 39 degrees with its abutments: its span in an oblique direction was 25 feet, and its rise 5 feet 6 inches. The only difference of construction is, that in common bridges the courses are all parallel with the abutments, and in the skewed arches they run obliquely to them. The face of the abutments making an oblique angle to the sides of the bridge, it became necessary

that the courses of the arch, except a few at the springing, should stand square, with the outside of the bridge; all these difficulties are, however, overcome by iron ribs, applied as in the present example.

Lary Bridge, near Plymouth, completed in 1827, is of cast-iron, and is built over the estuary of the river Plym, and connected with Plymouth Sound by the Catwater. The width of the estuary is from 500 to 600 feet; the tide rushes with a velocity of 3 feet 6 inches per second, and flows on an average 16 feet perpendicular.

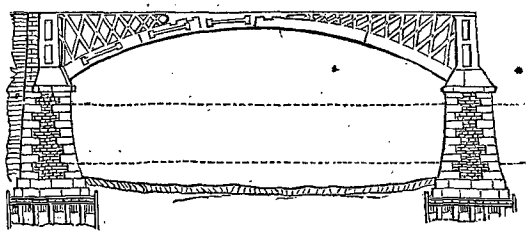


Fig. 509. ARCH OF LARY BRIDGE.

There are five arches; that in the centre spans 100 feet, and rises 14 feet 6 inches; the next are 95 feet span, and rise 13 feet 3 inches; the other arches are 81 feet span, and rise 10 feet 6 inches; the piers are 10 feet and 9 feet 6 inches; the roadway between the abutments is 24 feet wide, supported upon five cast-iron equidistant ribs, each at the springing 2 feet 6 inches deep, and at the apex 2 feet 2 inches. The masonry cost 13,365*l.*, and the iron-work 27,126*l.*

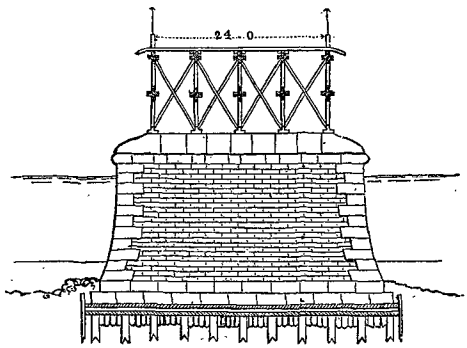


Fig. 510. SECTION THROUGH PIER.

Cast Iron Bridge over the Avon, 7 miles north of Tewkesbury, over which the Birmingham and Gloucester railway passes, was completed in the year 1840. This bridge has three arches, each of 57 feet span, and a versed sine of 5 feet 2 inches; the distance between the centres of the piers is 66 feet 6 inches, the breadth of the cutwaters 8 feet 6 inches, the clear water-way is 173 feet 6 inches.

The two piers are formed of cast-iron caissoons, filled in with solid masonry and concrete to the height of 12 feet; after which hollow masonry is used to support a capping plate of iron, on which is placed eight columns over each pier, supporting the entablatures and arches, all which are of cast-iron. The caissoons are 41 feet 6 inches in length at the base, and 16 feet in width; their ends are semicircular, and they taper upwards for 12 feet all round, the dimensions at the top being 34 feet 6 inches by 8 feet 6 inches, after which they rise perpendicularly 8 feet 9 inches. They have cast-iron flanched plates, of about $\frac{3}{4}$ of an inch in thickness, put together with screw-bolts and iron cement; each caissoon when put together contains about 28 tons of iron. The total weight of the iron work in this bridge is 520 tons, and the cost is stated at about 10,000*l.*

Cast-iron Bridge at Portumna, over the Shannon, which unites the counties of Galway and Tipperary. The total length is 558 feet 6 inches, exclusive of the island; the width between the railing is 17 feet.

The abutments are of masonry, of Portumna limestone, built with hydraulic mortar; the sheeting piles are of beech and larch, whilst the main piles and waling pieces which support the roadway girders are of Memel timber.

There are thirteen openings, each of 18 feet 6 inches span, between the Tipperary shore and the island, and twelve openings of a similar span between the island and the outer pier of the swivel bridge, which adjoins the Galway shore, and is 40 feet 6 inches span.

The cast-iron girders are 20 feet in length, 17 inches deep, and $1\frac{1}{2}$ inch thick, with a flanch at the top 8 inches wide, to receive the plates which carry the roadway; there is also another flanch at the bottom 4 inches in width. The roadway plates are $\frac{7}{8}$ of an inch in thickness, secured by bolts and plates put together with iron cement. On the outside girders, cast-iron plates are affixed, which carry the railing of wrought-iron; each girder was proved by passing along it a weight of 12 tons, whilst it was mounted on two piers at 20 feet apart. The swivel bridge has two leaves, with a clear opening of 40 feet.

The total cost of the bridge, including abutments, cofferdams, and superintendence, was 24,131*l.*, it was executed under the superintendence of Mr. Rhodes.

Suspension Bridges, of iron, do not appear to have been introduced before the year 1741, when one was built across the Tees for the use of the miners; its length was 70 feet, and was suspended above the level of the river at a height of 60 feet: Scamozzi "Del Idea Archi," published in 1615, conveys some notion of these structures, but their true principles were not made known till they obtained the attention of Bernouilli. Hutchinson, in his "Antiquities of Durham," gives the following account of the winch bridge:—"It is suspended on iron chains, and stretched from rock to rock, over a chasm 60 feet deep; its width is 2 feet, with a hand-rail on one side, and it is planked in such a manner, that the traveller experiences all the tremulous motion of the chains."

When Mr. Telford was called upon to report upon the practicability of forming a bridge at Runcorn, he commenced a series of experiments upon the tension of iron, and from that period engineers seem to have studied the principles of suspension bridges. These important experiments occasioned iron to be more universally introduced into construction; and we now find that the skill of the carpenter is not always required to cover in a building with timber.

Mr. Telford commenced his experiments by proving what force would pull asunder lengthwise pieces of iron from $1\frac{1}{2}$ inches to $\frac{1}{20}$ of an inch in diameter. The experiments

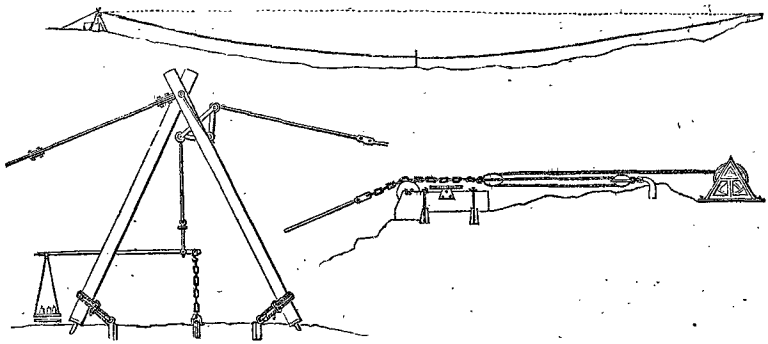


Fig. 511. MACHINE FOR PROVING THE STRENGTH OF IRON.

were made upon those of the largest diameter, by means of an excellent hydrostatic machine, and on those of the smaller by attaching weights perpendicularly, and repeating them at various times.

He then made several experiments upon different diameters, from $\frac{1}{10}$ to $\frac{1}{20}$ of an inch drawn horizontally, and with different degrees of curvature; and this was performed between points 900, 225, 140, and 139 feet 6 inches apart, and was repeated 200 times. In the experiments made upon $\frac{1}{10}$ of an inch and under, the wire was drawn over pulleys; sometimes both ends were fixed, and sometimes one end only, the other having weights attached perpendicularly to show the effects when compared with those loaded upon the curved part of the wire; these last were disposed at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ divisions of the distance over which it was stretched. These experiments being completed, it was ascertained what blow would break the wire when stretched nearly horizontally and at different curvatures, which was done by dropping weights from a given height. The several wires were weighed, and the weight of 100 feet in length of each noted.

The result of the experiments was, that a bar of good malleable charcoal-iron 1 inch square will suspend 27 tons, and that an iron wire, $\frac{1}{10}$ of an inch in diameter, 200 feet in length, weighing 3 pounds 3 ounces, will suspend 700 pounds; and that the latter, with a curvature or versed sine of $\frac{1}{50}$ part of the chord line, will support $\frac{1}{10}$ of the weight suspended perpendicularly, when disposed equally at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ its length, and with a curvature of $\frac{1}{20}$ of the chord, it will bear $\frac{1}{3}$ of the aforesaid perpendicular weight disposed in a similar way. A wire $\frac{1}{10}$ of an inch in diameter, drawn very tight between points, 31 feet 6 inches apart, resisted the impulse of 20 pounds weight, falling from a height of 7 feet 9 inches.

A bar of good English malleable iron 1 inch square will suspend from 27 to 30 tons before it breaks, and will bear from 15 to 16 tons before its length is at all extended. With a curvature of $\frac{1}{20}$ of the length, malleable iron, besides its own weight, sustained $\frac{1}{3}$ of what broke it perpendicularly. An inch bar would therefore bear $\frac{1}{3}$ of 15 tons without deranging its parts; but it is better in practice to assume that an inch square in section should only bear 4 tons.

Galashiel Bridge was constructed in the year 1816, at a cost of 40*l.*, and is 112 feet in length; it is suspended from iron wires of very small diameter.

Peebles, over the Tweed, called King's Meadow Bridge, was constructed in 1816, for the

sum of 160*l.*; its length is 110 feet, and its breadth 4 feet. Columns of cast-iron 9 feet high, fixed securely in the soil, were placed at each angle of the bridge, and supported the suspending wires, which were $\frac{3}{10}$ inch in diameter. The floor is carried by five oblique wires, which are secured to an iron bar 10 feet in height, and of a sectional area of $2\frac{1}{2}$ inches, inserted in the top of the column; the way over is formed of frames of wrought-iron covered with $1\frac{1}{2}$-inch deal; on each side are chains, which serve as ties, of $\frac{3}{4}$-inch iron; the length of the links is 5 feet, they are fixed at one end into masonry underground, and at the other to the iron bar inserted in the columns, which prevents them from being pulled over.

Dryburgh Bridges were erected in the year 1817, about 18 feet above the low water of a torrent. The supports were 260 feet from each other; and about a year after its erection it was destroyed by a high wind, which gave an undulating motion to the roadway, and at last broke the suspension chains. A new bridge, which cost 720*l.*, was immediately commenced, with perpendicular suspension rods $\frac{1}{2}$ inch in diameter, having at the top a cross-head, by which they were kept between the oval links of the suspension chains; at the lower end they pass through the side beams of the flooring, to which they are screwed. Chains of nearly 1 inch in diameter pass under the roadway, and extend from one abutment to the other. On each side a diagonal trellis firmly joined together forms a parapet, and prevents the effects of any undulatory motion. The two suspension chains are each $1\frac{5}{12}$ inches in diameter, and the length of the bars composing them is 10 feet. At each extremity of the bar is an eye, through which passes an oval ring 9 inches in length, connecting the two contiguous bars; these suspension chains are secured to the head of wooden pillars 28 feet high above the level of the roadway; the space between them, which forms the approach to the bridge, is 9 feet. The two pillars at the extremities are connected by braces forming a St. Andrew's cross, and by transverse beams, over which the suspension chains rest; each pair of chains is 12 feet distant from the other where they pass over the pillars, and only 4 feet 6 inches in the middle of the bridge. By this arrangement they obtain an oblique power, both horizontally and vertically, and thus prevent, to a certain degree, any oscillatory motion.

The suspension chains are under the platform, which they support by upright rods of cast-iron, kept in their places by small arches of the same material, in a horizontal line under the flooring, also of cast-iron, over which is a layer of small stones. The chains pass over each abutment, descending behind it, and are secured in masonry where a passage is left to examine and repair them. The lower extremity of the chains rests upon the base of a conical tube of cast-iron, through which it passes, and the tube being strongly bedded in the masonry keeps it secure.

Suspension Bridge over the Tweed, at Kelso, in Scotland, was finished in July, 1820, by Captain Brown. It is 300 feet in length, and 18 feet in width, and has a carriage-road in the middle; the total cost, including the masonry, timber, and iron-work, was only 50,000*l.*

The roadway, 27 feet above the level of low water, presents a gentle rise towards the middle, where it is 2 feet higher than at the extremities. There are twelve suspension chains, arranged in pairs; the diameter of the iron with which they are made is 2 inches. The links are composed of bars 15 feet long, terminated with an eye at each end; two short flat links are applied at each side of the two contiguous bars, and bolts well-riveted traverse the two links as well as the eye of the bar. The vertical suspension rods are 1 inch in diameter, and pass through a saddle-cap; the bolts are cylindrical, having for their base an ellipsis, the two axes of which are 2 inches and $2\frac{1}{4}$ inches. The three chains are placed almost perpendicularly over each other, and the suspension rods are fastened first to the upper, and next to the middle chain, and then to the lower. The chains which correspond with each other right and left of the bridge have their joints so placed that the suspending rods also perfectly correspond. The lower ends of the suspension rods traverse a longitudinal piece of iron, at the extremity of which the timbers for the floor rest, and under which the rod is strongly riveted. The timbers are 15 inches deep and 7 inches wide, and are covered with plank 4 inches thick.

The parapets are formed into lozenges, the sides of which are 6 inches; the height is 5 feet. The distance between the points of support for the chains is 437 feet, although that between the abutments is only 360 feet; the angle formed by the chains with the vertical line at the points of suspension is equal to 78 degrees. The weight of each chain, with its suspending rods, bolts, links, &c., is about 900 pounds. The twelve chains and all the iron-work used in the bridge weighs 13,000 pounds.

The masonry of the abutments against the steep rock which borders the river is 20 feet high, and the isolated pier on the other side is 60 feet, and of a pyramidal form; its thickness is 17 feet 6 inches, and at half its height the width is 36 feet; it is square at the bottom to the height of 10 feet, when the slope commences diminishing about a twelfth part. The road passes through this pier by an arched gateway 12 feet wide and 17 feet high. The pairs of chains run through the masonry of the piers, the openings for which are 2 feet wide,

above the other. They pass over rollers on the English side of the river, and cast-iron bedded in the masonry on the other; the rollers have axles resting on iron embedded in the masonry, and the chains, instead of being formed of bars 15 feet long, are composed of very short links, so that they may work freely over the rollers. After the chains have traversed the masonry of the piers, they are further strengthened by long links passing 31 feet underground, and are attached to masses of cast-iron 6 feet long, 5 feet wide, 5 inches thick in the middle, and 2½ inches at the edges; to these they are secured by strong iron bolts, and the masses of iron are loaded with stone to the level of the road; the corresponding masses on the English side of the river are not buried as on the other, but are above the level of the foundation of the piers. They are placed nearly vertical, corresponding with the strain of the chains. A horizontal arch, the stones of which are embedded in the rocks, keeps the iron plates in their right position.

Menai Bridge, over the strait which separates the Isle of Anglesea from the county of Caernarvon; erected by Mr. Telford.

The work was commenced in May, 1819, and the rock called Ynys-y-moch, which was accessible at low water, was, by blasting, brought to an even surface; on this was laid the foundation for the west main pier on the Anglesea side. A temporary causeway, on which

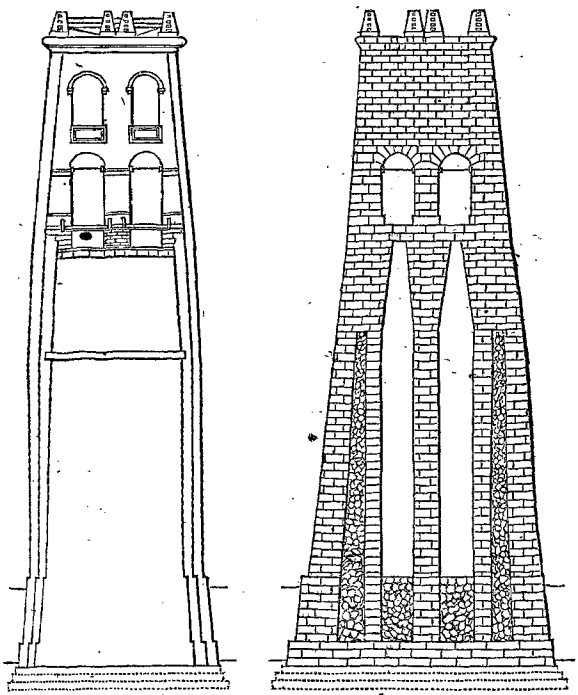


Fig. 512. TRANSVERSE SECTION AND ELEVATION ON THE CAERNARVON SIDE.

was a railroad for sledges, drawn by horses, was made, at a considerable elevation above the level of high water, over the space between the Anglesea shore and the rock.

The tide through the strait runs with great velocity, and being now shut out, the current in the centre of the channel is greatly increased in velocity. The rise at ordinary spring tides is about 22 feet; it sometimes exceeds 30, and winds from the range of mountains in the vicinity of Snowdon are frequently strong and violent; the breadth of the estuary at high water is 918, and at low water 480 feet.

The first stone was laid upon the Ynys-y-moch rock on the 10th of August, 1819, and in the autumn of the same year the main pier on the Caernarvon side of the strait was commenced; the beach, being first excavated to the depth of 7 feet where the solid rock sustains the east main pier, a greater mass of masonry is given to the foundations of this pier than to the other on the Ynys-y-moch rock.

The height of the main piers, from the level of high water spring tides to the roadway, is 100 feet; from that of low water spring tide 121 feet; from thence to the top 53 feet.

The two arches, through which the road passes, are 9 feet in width, and 15 feet to the springing of the arches.

The width of the piers, taken on the transverse section at the base, is 66 feet 3 inches; at the set-off, above the high water line, 58 feet 2 inches, diminishing at the top to a width of 33 feet 8 inches, as measured at the bottom of the hollow which forms the cornice or capping. Their depth, as measured in front, immediately above the set-off, above the high water line, is 40 feet 1½ inches. The construction of the pier is exhibited in the sections.

The resident engineer was Mr. W. A. Provis, the prover of the iron-work Mr. J. Provis, the contractor for the masonry Mr. J. Wilson, the iron-founder Mr. Hazeldine, and the superintendent engineer of the iron and timber work Mr. T. Rhodes.

The masonry of the piers above the level of the roadway was strengthened by drilling holes through the stones of each course, and, after the insertion of iron bolts, fixing them with Parker's cement; wherever arches spring over the roadways, iron horizontal ties were introduced to prevent any spreading. In May and June, 1824, the two pyramidal piers were constructed, and the cast-iron saddle plates fixed on their summits.

The Abutments, Piers, and Arches were commenced in the year 1820, and by March, 1822, all the piers were carried up to the level of the springing course, and the centres for the arches fixed; by the end of the year, the whole of the arches were turned, and the spandrils built to the level of the cornice.

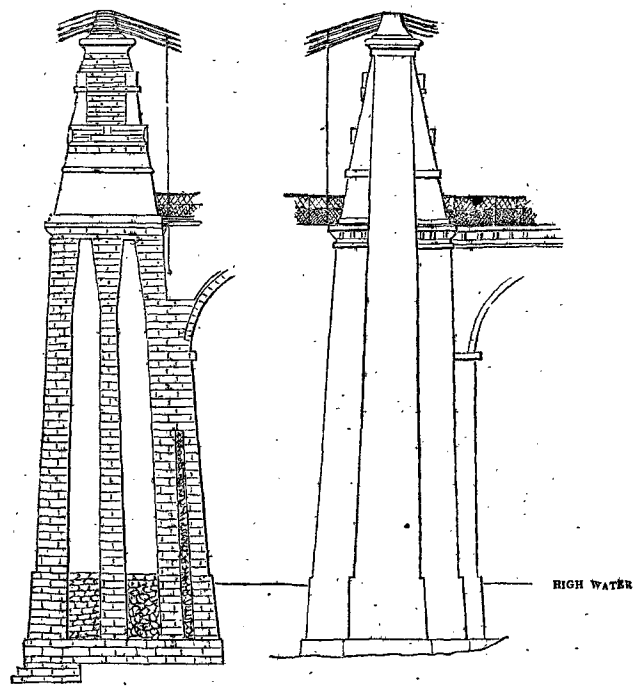


Fig. 513. SECTION AND ELEVATION OF MAIN PIER.

The span of the side arches is 52 feet 6 inches, and their versed sine 26 feet 3 inches, forming semi-circles; the height of the small piers above the level of high water, to where the arches spring, is 65 feet.

There are four of these arches on the island side, and on that towards Caernarvonshire three; the distance from the centre of one pier to that of the other is 579 feet 10¼ inches.

The span of the catenary is 570 feet, and its versed sine 43 feet.

Materials employed. — *For the masonry* the grey marble was employed, which was obtained on the shores of Penmon, at the north-east extremity of the island of Anglesea, 7 miles from Beaumaris, and the price paid by the government to Lord Bulkley was 6*d.* per ton.

This fine stone bears a beautiful polish, and the natural layers or shelves afforded blocks of any required dimensions, which could be drawn from the quarry without blasting; it

was removed by small vessels from the Bay of Beaumaris to Bangor Ferry, a distance of 12 miles.

The iron was all of the best Shropshire manufacture, supplied from Upton Forge, by Mr. Hazeldine of Shrewsbury. The bars were repeatedly drawn between cast-iron rollers, grooved in various shapes, and afterwards proved at the works, previous to being shipped for the Menai Straits.

An accurate and powerful machine was used for proving each bar, which was tested by a strain of 11 tons to every square inch of transverse section; during the trial, it was frequently struck by a hammer, and its length was observed by an unvarying iron gauge. After proof, each piece of iron was cleansed, put into a stove, at a gentle heat, and then immersed in a trough containing linseed oil, where it remained for a short time, and was again returned to the stove, when, after drying, it came out covered with a varnish, upon which a coat of oil paint was added, and it was sent off to the works.

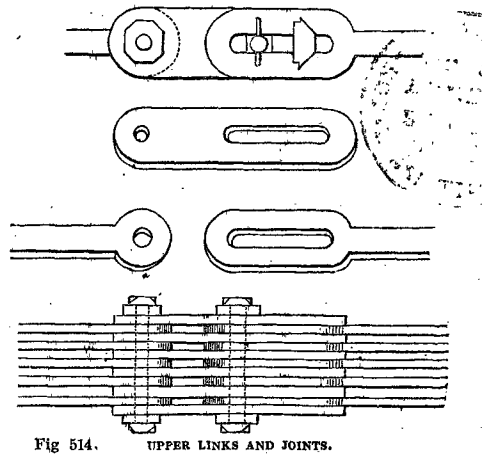


Fig 514. UPPER LINKS AND JOINTS.

Iron work. — There are four sets of main chains, each composed of four: so that there are altogether 16 chains, which have a similar and uniform tension. Each consists of 5 chain bars in length, each 10 feet long, 3¼ inches wide, and 1 inch in thickness, with 6 chain plates at each end 16 inches long, 8 inches broad, and 1 inch thick; the joints being secured by 2 bolts weighing ½ cwt. In the cross section of the chain there are 80 chain bars, and the number there in one chain is 935, in the sixteen, 14,960.

The entire length of the chains is 1710 feet from where they are fastened to the rock on each side.

The number of chain plates to each chain is 1122, in all 17,952; each chain has 374 bolts, amounting in all to 5984.

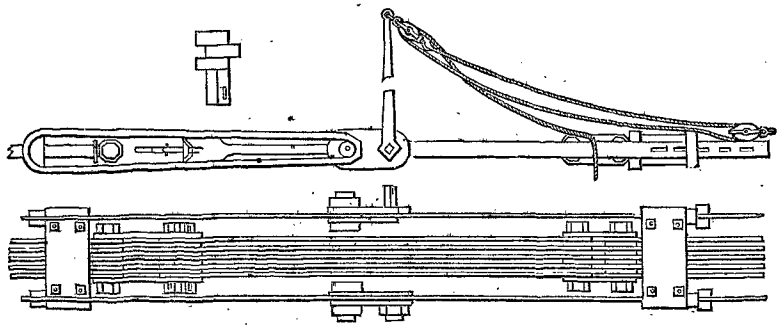


Fig. 515. FOR TIGHTENING THE MAIN CHAINS.

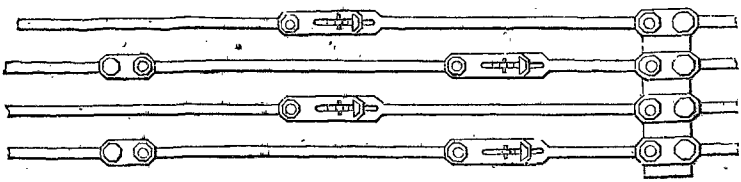


Fig. 516. ELEVATION OF CHAINS.

The vertical rods suspended from the chains are placed 5 feet distance apart, and are 1 inch square; there are 199 to each line, and in the whole four lines 796. These carry

111 sleepers; the number of trussed rods and king-posts which support the suspended road is altogether 444.

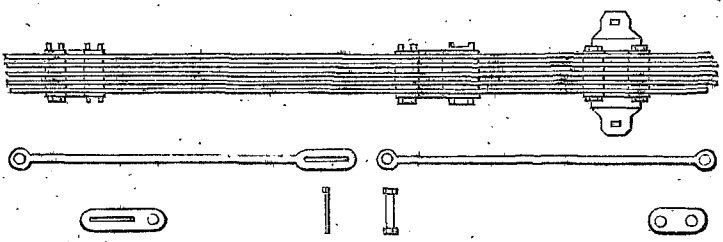


Fig. 517. PLAN OF CHAINS.

Iron frames to which the suspension chains are made fast.—Three oblique circular cavities were blasted in the solid rock on the Anglesea side, 6 feet in diameter, care being taken to leave a considerable portion of rock between the openings; through these the suspension chains pass down an inclined plane of not less than 60 feet in length.

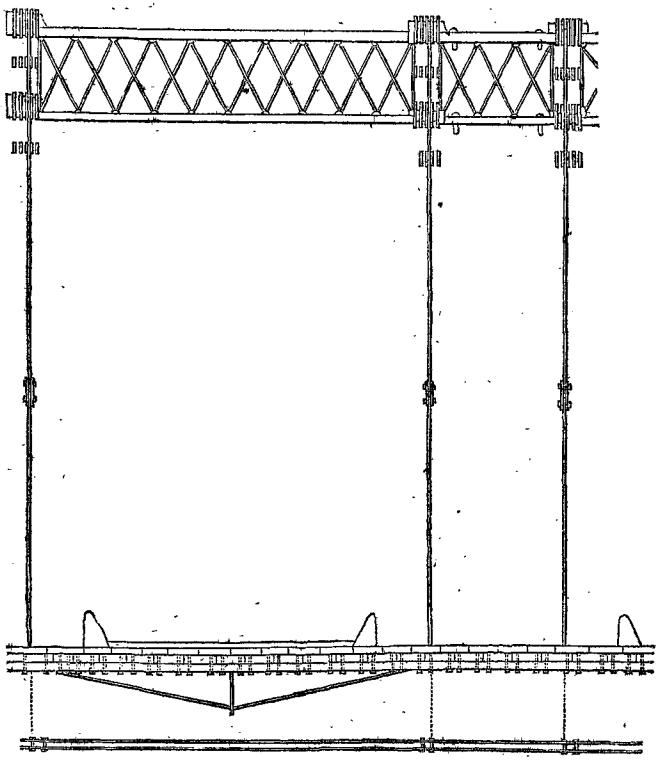


Fig. 518. SECTION THROUGH MAIN CHAINS AND ROADWAY.

At the lower ends of these inclined tunnels is another at right angles, which connects them together, through which the workmen passed to fix the iron plates into the natural rock, and a passage is left on the south-west side of the bridge, which communicates with these subterraneous chambers.

On the Caernarvonshire side there is the same arrangement, but the depth of earth was considerable before the native rock could be arrived at, which occasions a different length to be given to the catenary on this side to that on the other.

The flat cast-iron plates were let into the natural rock, and so firmly secured that they

are perfectly immoveable, and, unless the entire mass of rock were to give way, would bear any stress that might be given them.

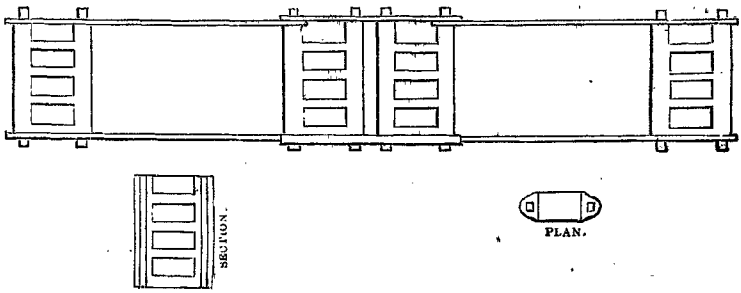


Fig. 519. SADDLES AND TIES FOR CARRYING CHAINS.

The saddles and ties which carry the main chains through the front of the Caernarvonshire toll-house are formed of cast-iron plates; they are 3 feet 5 inches wide; the holes through which the chains pass are 2 feet 4 inches in width; the four plates, with the passage for the sixteen chains, are admirably put together, two being in the middle, and one at each extremity; the cast-iron blocks or saddles are 8 feet 7 inches in width across the bottom, in the direction of the chains, and 7 feet in height, the spaces between the four bars which hold the chains being each 7 inches. These saddles were all cast with holes, in order that the tackle might be adjusted and attached by which they could be hoisted. The frame for raising these castings was made of timber; the platform at bottom was 30 feet in extent, and its total height was 74 feet; an additional timber was fixed to the sides to a height of 26 feet; the blocks were secured by ropes to the top, and passed as shown in the figure, which represents the action of elevating a part of the iron work. At the side is a section of the frame-work, to the top of which is attached two guy-ropes.

There was also an ingenious machine or clam made use of for holding the ropes of the hoisting tackle whilst fleeting them on the capstan, and which was found of the most essential service. The plan of the saddles shows their position; the parallelogram, upon which the four are placed, measures 37 feet 6 inches in length, and 14 feet in width.

The plan of the great pyramid exhibits the planking of the two carriage-ways. The mass of masonry in the middle is 6 feet in width; the space for the traffic on each side 9 feet, and the thickness of the exterior walls at the greatest 9 feet, and in the less 6 feet. The pavement, as it is laid over the planking, is partly shown in the figure. The trans-

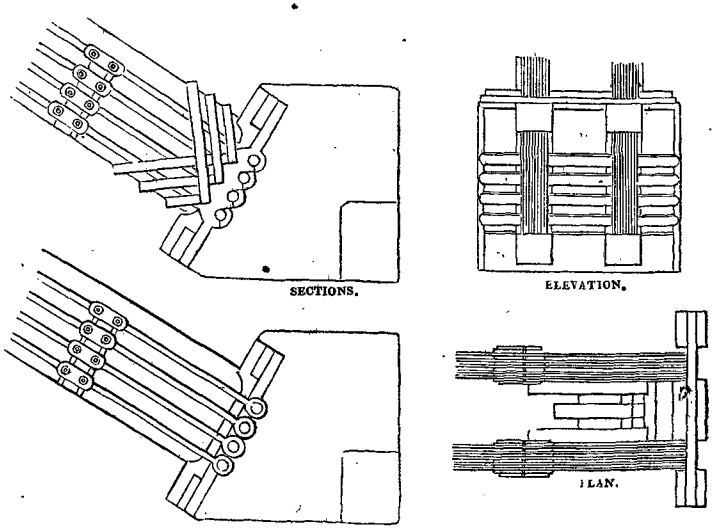


Fig. 520 METHOD OF SECURING MAIN CHAINS TO THE ROCK.

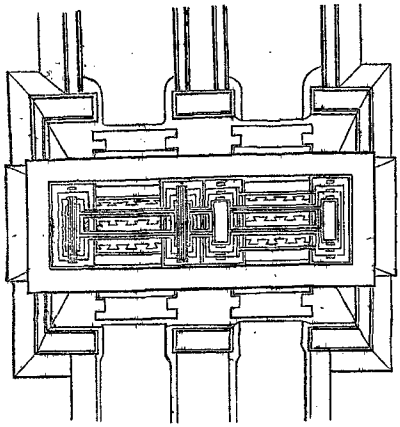


Fig. 521. PLAN OF THE SADDLES.

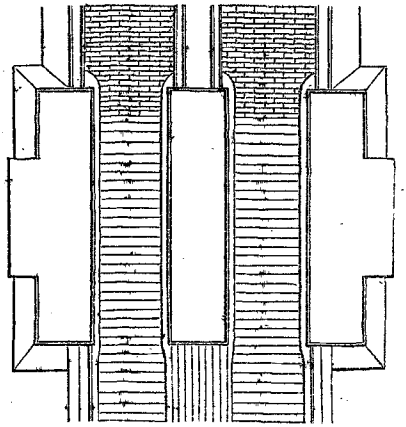


Fig. 522. PLAN OF GREAT PYRAMID.

verse section through the main chains, exhibiting a little more than one half of the entire width; the middle footway and one passage for carriages, also represents the position of the several lines of chains where they cross or pass over the saddles; the sections and elevation of the main pier show the position of the main chains in the other direction, or in a line at right angles with the passage across the stream.

The suspension chains were first firmly secured to the flat cast-iron plates; the chain bars, each 10 feet in length, were then laid down by placing the five together, which constituted one breadth; and the consecutive lengths were thus carried on, united by flat iron plates and bolts, until the apex of the suspension piers was arrived at, the whole chain being supported by a timber framework placed underneath.

On the apex of each of the suspension piers was a cast-iron saddle, in which were wrought-iron rollers and brass bushes, which as the temperature varied allowed some play to the chains, and regulated any contraction or expansion of the iron; as the rollers were self-acting, no derangement could very well take place from this cause.

Mr. Davies Gilbert furnished Mr. Telford at various times with information highly useful for the completion of this bridge; that gentleman calculated the dimensions to be given to the several bars of a catenary arch formed in iron or steel upon the suspension principle. He assumed the tenacity of iron to be 50,000 for a square inch, and its specific gravity 7·8, and Mr. James Jardine formed the following table for the construction of the chains. The first column shows the distance between the points of support; the second, the length of curve, or chain, between the points of support; the third, the axis of curve, or versed sine, of the chain; the fourth, the angle, nearly, between horizontal line and curve, at the point of support; the fifth, the tension, or strain, on each chain by its own weight, at either point of support; the sixth, the tension or strain on the sixteen chains by their own weight, at either point of support; the seventh, the weight of one chain; and the eighth column the weight of the sixteen chains.

Feet.	Feet.	Feet.	Angle.	Tons.	Tons.	Tons.	Tons.
500	565·6	35	14° 0′	20·87	333·9	10·10	161·6
560	567·5	40	15 54	18·53	296·5	10·13	162·1
560	569·5	45	17 52	16·57	265·1	10·17	162·7

The transverse section through the main chains and roadway shows the positions of the several parts, and the cast-iron pipes 3 inches in diameter, strutted or braced with diagonal bars; within the pipes is a wrought-iron bolt, 1¼ inch in diameter, which connects together the four lines of suspending chains. The footpath in the middle of the transverse section is 4 feet in width, and the two other divisions are each 12 feet: between the oak guards of each carriage-way is a width of 7 feet 6 inches; the iron truss-rods and king-posts introduced beneath the roadway bars add very considerably to the strength of the platforms.

In the arrangement of the several parts of this bridge the greatest attention was paid to the manner in which they were united together, and also to allow of any portion being taken out and reinstated, in case of accidental fracture or injury of any kind; in this stupendous undertaking the constant stress upon particular parts, where destructive in its effects, could be easily remedied without endangering the entire work.

The chains were supported on the scaffolding, whilst the lengthening took place on the Caernarvonshire side, until the chain bars, suspended from the apex in a perpendicular direction, nearly reached the level of high water mark.

The most difficult part of the whole operation then commenced, that of conveying the first suspension chain across the Strait, and making a junction; this was performed on the 26th of April, 1825.

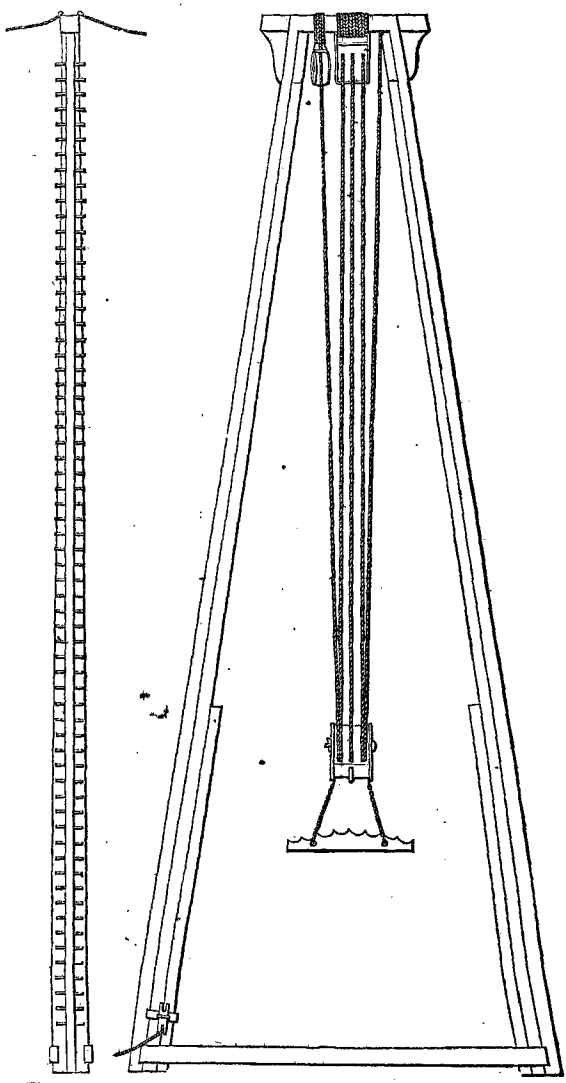


Fig. 523. FRAME FOR RAISING CASTINGS ON TO THE PYRAMIDS.

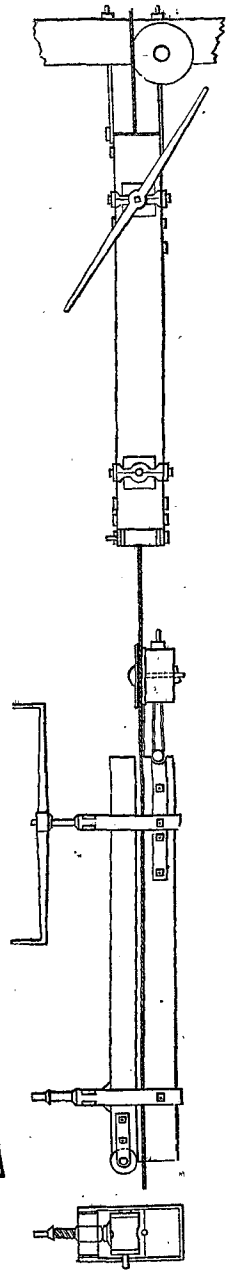


Fig. 524. CLAM FOR HOLDING THE ROPE OF THE HOISTING TACKLE WHILST FLEETING IT ON THE CAPSTAN.

At half flood tide, a raft prepared for the purpose, which carried the portion of the chain intended to be drawn over, was moved from Trebroth Mill, on the Caernarvonshire side, by four boats assisted by the tide, to the centre of the river, and between the two main piers, where the raft was made fast to several buoys, anchored for the purpose. One

end of the chain was then made fast to that which hung perpendicularly from the apex of the pier, on the Caernaryonshire side. The other end of the chain to be suspended was

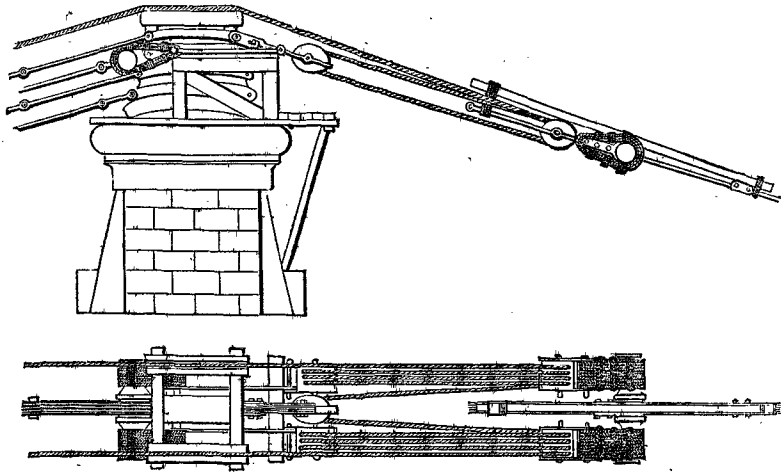


Fig. 525. MAIN TACKLE FOR RAISING THE CHAINS.

fastened to two blocks of great power, the tension of the chain at this time being equal to 40 tons.

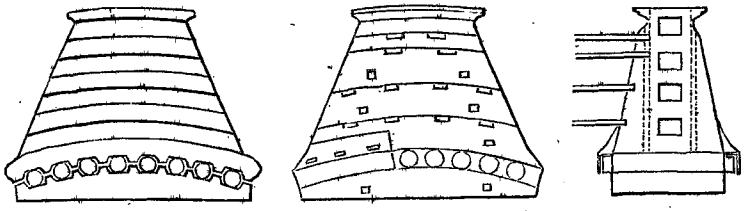


Fig. 526. SADDLES FOR CARRYING THE MAIN CHAINS. SECTION.

After the blocks were made fast to the chain, two capstans and two preventive capstans, each worked by 32 men, commenced raising, and within two hours and twenty minutes from the movement of the raft from the shore the last bolt was fixed, which completed the entire length of the first chain, three of the men employed passing along it. And by the 9th of July the other fifteen chains were secured, and the entire line of suspension completed.

Vertical rods.—These are placed at equal distances of 5 feet, and are fastened to the sixteen suspension chains. The iron sleepers or transverse roadway bars are bolted to the lower ends, and to each of these 111 sleepers four vertical rods are attached transversely, making altogether 444.

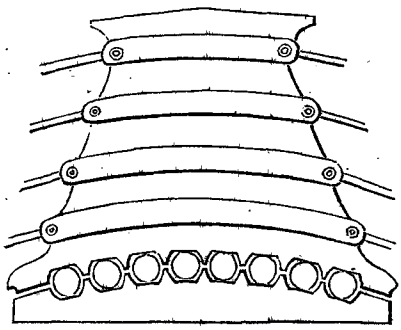


Fig. 527. SADDLE.

Timber roadway.—The first tier of planks was laid across the iron sleepers on the 24th of September, 1825, there being three altogether, the lowest 3 inches thick, the middle and upper each 2 inches; the last is laid transversely to the width of 8 feet, with side guides to prevent any injury from the carriage wheels. The planks are all spiked together, and between each layer was a coating of Borrodaile's patent felt saturated with boiled tar.

Weight of the Iron.	*Lbs.*
64 large chain bars, each 7½ feet long, 4 inches wide, 1½ inches thick, and each bar weighing 150 pounds; for the five	48,000
384 chain plates, 18 inches long, 10 inches broad, 1½ inches thick, and each weighing 126 lbs.	28,000
128 large bolts, each weighing 126 lbs.	16,128
123 chain bars, 10 feet long, 3¼ inches wide, 1 inch thick, each weighing 124 lbs.; for the five	76,260
738 chain plates, 16 inches long, 8 inches broad, and 1 inch thick, each weighing 32 lbs.	23,616
246 bolts, each weighing 56 lbs.	13,776
597 connecting rods and bolts, each weighing 37 lbs.	16,119
16 steadying ties, each weighing 1225 lbs.	19,600
Total weight of one chain (121 tons 299 lbs.)	242,299
And for the whole sixteen chains, 3,876,784 lbs., or 1,938 tons 784 lbs.	
2 cast-iron plates under the saddles, each weighing 46,080 lbs.	92,160
8 saddles, each weighing 3248 lbs.	25,984
20 tie bars for the saddles, 20 feet long by 3 inches square, each weighing 600 lbs.	12,000
64 rollers, each weighing 335 lbs.	21,440
16 guide plates and brass bushes, each 373 lbs.	5,968
199 suspension rods, averaging 33½ feet in length, 1 inch square, and each rod weighing 111 lbs.; for the four sets	88,356
111 sleepers, each weighing 334 lbs.	37,074
222 trussed rods, each weighing 40 lbs.	8,880
222 king posts, each weighing 7 lbs.	1,554
Anglesea side. Suspended portion, 98 side rails, each of 80 lbs. weight	7,840
Anglesea side. Suspended portion, 98 foot rails, each of 50 lbs. weight	4,900
Anglesea side. Suspended portion, 222 side rails, each of 10 lbs. weight	14,430
Caernarvon side. 74 side rails, each of 65 lbs. weight	5,920
Caernarvon side. 74 foot rails, each of 50 lbs. weight	3,700
6 cast-iron frames for fastening in the rock, each weighing 2240 lbs.	13,440
24 round bolts, 9 feet by 6 inches, each weighing 444 lbs.	10,656
Side of Anglesea. 78 side rails of road, weight 80 lbs. each	6,240
Side of Anglesea. 24 centre do. weight 50 lbs. each	1,200
Side of Anglesea. 78 cast-iron stanchions to support rails, weight 176 lbs.	13,728
Side of Anglesea. 24 do. weight of each 100 lbs.	2,400
Side of Anglesea. 39 hand-rails, weight of each 104 lbs.	4,056
Side of Caernarvon. 38 side rails of road, weight 80 lbs. each	3,040
Side of Caernarvon. 40 cast-iron stanchions, weight of each 176 lbs.	7,040
Side of Caernarvon. 38 hand-rails, weight of each 104 lbs.	3,952
484 cast-iron parapet rails, weight of each 31 lbs.	15,004
4 sets of cast-iron saddles, weight of each 2016 lbs.	8,064
8 gate posts, weight of each 533 lbs.	4,264
4 toll gates, weight of each 325 lbs.	1,300
2 lamp-posts, weight of each 300 lbs.	600
12 tie bars in the pier arches, weight of each 533 lbs.	6,296
32 cast-iron saddles about the toll-house on the side of Caernarvonshire, weight of each 416 lbs.	13,312
4 plates under the last-mentioned saddles, weight of each 900 lbs.	3,600
240 segment saddle bars on the piers, and near the Anglesea toll-gate, weight of each 200 lbs.	48,000
	496,468
Add to this the weight of the sixteen chains	3,876,784
Total weight of iron	4,373,282

Or 2186 tons, 1282 lbs.

Conway Bridge is upon the same principle as that over the Menai Strait. The distance between the points of suspension is 327 feet; the depression or versed sine of curvature of the main chains is 22 feet 6 inches; the number of chains is eight, each having five bars, 3¼ inches by 1 inch, making together a total of 130 square inches of transverse section. The roadway is in breadth 17 feet 6 inches, and is 15 feet above the level of high water; it consists of a carriage-way without any separate footpath.

The main chains were hoisted in the following manner; six strong rope cables were stretched across the tops of the supporting pyramids, which were made to carry a temporary platform; on this was laid the chain which was to be united with that portion to be brought up from the fixed points in the rock galleries to the top of the pyramidal towers. When this junction was made, the platforms of wood were removed, the rope cables were slackened, and the chain lowered to its proper curvature. The side railing was then fixed, and the road platform constructed in a similar way to that over the Menai, the several parts of the chains, and method of fixing them, being alike.

The Union Suspension Bridge, over the Tweed, five miles from Berwick, constructed by Capt. S. Brown, R.N., was the first large bar chain bridge executed in Great Britain; it was finished about 1820.

The chord line, or distance between the points of suspension, is 449 feet, and the deflection 30 feet. There are twelve main chains placed in pairs, and forming three ranges, one under the other, on each side of the bridge, and about 19 inches apart. Each link is formed of a rod 2 inches in diameter, and 15 feet in length, with an eye at each end for welding. On the Scotch side of the Tweed the suspension pier is of ashlar stone, formed like a pyramid, 60 feet in height, 36 feet in breadth, and 17 feet 6 inches thick at bottom. The arched opening is 12 feet wide and 17 feet high. On the other side of the river the pier is built on the rock, which is precipitous. The roadway is 387 feet in length, and 18 feet wide between the parapets, and is supported by vertical rods, 1 inch in diameter, and placed 5 feet apart. The chains contain 38 square inches of iron, and its strength has been computed equal to bear 1104 tons.

The Newhaven Suspension Pier was also erected by Capt. S. Brown, R.N., in 1821, by order of the Trinity Pier Company; its extreme length is 700 feet, and its width 4 feet. It has three divisions, each 209 feet span, with 14 feet deflection. The pier-head is 60 feet wide, and 50 feet long, supported upon 46 piles driven about 8 feet into the clay. The land pier is of solid masonry, 6 feet square, and 20 feet high; the main bars pass over the top, and the back-stays form an angle of 45 degrees to the chord line. There are two main chains formed of rods 1 inch and $1\frac{1}{4}$ inch in diameter, and 10 feet in length. The roadway is supported by two longitudinal iron side bars, which are held up by the vertical rods. The cast-iron standards that support the main chains are triangular frames cast in one piece, and the main chains lie on cast-iron saddles.

Brighton Chain Pier, opened in November, 1823, was designed by Capt. S. Brown, R.N., who first suggested that the chains should be made of straight wrought-iron rods or bars, from 5 to 15 feet in length, with either welded eyes, or holes drilled at their ends, by which they might be connected either by short links or pins; this invention he patented in 1817.

The Brighton pier extends into the sea 1014 feet from the face of the esplanade wall, and its entire length is 1136 feet, formed with four openings, each spanning 255 feet, with a deflection of 18 feet. The extreme breadth of the platform is 13 feet, and in the clear width 12 feet 8 inches.

The pyramidal suspension towers are made of cast-iron, united by an arch at the top; they are 10 feet apart and 25 feet high, and each weighs about 15 tons: they are placed on piles driven firmly into the chalk, which stand out about 13 feet above high water; these groups of piles are 256 feet distant from each other, and leave a clear opening of 227 feet. The pier-head has the form of a T, and 150 piles were used, besides braces and diagonals; over them the platform is 80 feet by 40 feet, which is paved with granite 12 inches thick, the weight of which is upwards of 200 tons.

Each of the ordinary groups of piles consists of twenty. The four main chains on each side, which carry the platform, are formed of wrought-iron, round eye-bolts, about 2 inches in diameter, 10 feet long, and weighing 112 lbs. each; they are united by open coupling links $1\frac{1}{2}$ inches deep, and 1 inch thick, with bolt pins 2 inches in diameter. The total area of the section of the iron in the chains is 25 square inches. The platform is suspended by vertical rods 1 inch in diameter and 5 feet apart.

Montrose Suspension Bridge, over the River Esk, was completed in the year 1829. The iron work was provided by Captain Samuel Brown for the sum of 9430*l.*, and the masonry of the towers cost 9080*l.*; this was exclusive of the land arches, which were a part of the old bridge.

From the centre of one tower to that of the other was 432 feet; the deflection of the chain, or versed sine of the catenary, 42 feet; the length of the suspended roadway 412 feet, and the width 12 feet; height of the roadway above the low water line 21 feet, and that of the towers 68 feet. The dimensions of the base of the tower at the level of the roadway are 40 feet by 20 feet; the archways through them 16 feet in width, and 24 feet in height; they are built of red sandstone ashlar, and are carried on piles. On each side were two main chains 12 inches apart, each composed of four bars of iron 5 inches in width, 1 inch in thickness, and 10 feet in length, united by plates and wrought-iron pins. The roadway was suspended by $1\frac{1}{4}$-inch perpendicular rods, placed 5 feet apart; these had at their lower ends stirrup irons, which carried cast-iron bearers, over which the road was formed. A

flooring of 3-inch plank, well caulked, was laid upon these bearers, and then 1¼ inch boarded floor above, laid transversely; over this was a fine coating of sand and gravel, cemented by tar.

There were no joints to the suspending rods, and the main chains rested upon detached cast-iron saddles, built into the masonry of the towers, and their ends were secured by cast-iron plates let into the masonry 10 feet under ground. The roadway of this bridge, which weighed 203 tons 9 cwt., was destroyed on the 11th of October, 1838, when the platform fell in one mass, in consequence of the failure of the suspension rods, which having no joints were twisted off close to the floor by the undulatory motion. It was afterwards repaired, when suspension rods of 1⅛ inch diameter were introduced, with flexible joints at the level of the platform.

Cross timbers were introduced instead of the cast-iron bearers; these were of Memel, 13 inches by 3½, laid edgeways and bolted together, as well as trussed with an iron rod 1⅛ inch in diameter; every sixth beam was trussed on the under side to give it more strength. Each side of the carriage-way, both above and below the cross beams, was bolted to two sets of longitudinal timbers, four in each set, and at every 10 feet they were united together by cast-iron boxes.

The planking of the footway was composed of battens 2 inches in thickness, laid transversely, and that of the roadway of four thicknesses of 2 inch Memel, over which was laid gravel, sand, and tar. During the storm which destroyed this bridge, the undulatory motion was observed to be the greatest at about midway between the towers and the centre of the roadway, but the waves of the platform did not follow those of the chains; no oscillatory motion was seen either in the roadway or in the chains; after the event, the chains, saddles, and fastenings were all found quite sound. The weight of the new roadway was 226 tons, 17 cwt., or 47·5 pounds per square foot.

The platform is 212 feet in length, and 27 feet in width, and cost 4026*l.*, or 7*s.* 3*d.* per foot superficial. The injury done to the bridge by the storm was the cause of many precautionary measures being resorted to, not only for preventing any upward heave, but also to confine, as much as possible, the undulatory motion: in the first suspension bridges these principles were entirely neglected; the idea of the roadway being lifted up from a force exerted beneath it does not seem to have suggested itself. The weight of the structure, it was supposed, would always be sufficient to counteract any upheaving: but on the repairs being entrusted to Mr. Rendel, he was led to conclude that the wind might act at the same moment on the upper side at one end, and the lower side at the other; therefore, unless the platform had considerable rigidity, undulation commenced, and then oscillation; to counteract this effect, a mode of trussing which should withstand this action was necessary. Here is adopted a system of vertical diagonal trussing 10 feet in depth, 5 feet above, and 5 feet below the platform, which effectually prevents undulation as well as oscillation.

The stretching strain, of malleable iron bars, is found to be three-fourths of the breaking strain, or, as some experiments have proved, nearly one half. Iron bars 1 inch square stretch when 16 tons is applied to them, so that the stretching strain may be fairly taken as six-tenths of their strength, and they will support 9 tons per square inch without stretching at all. Mr. George Rennie has shown us, however, that the ultimate strength of cohesion of cast steel is 134,256 pounds per square inch.

Hammersmith Suspension Bridge, erected after the design of W. Tiernay Clark, forms a communication from the Surrey side of the Thames with Hammersmith; it was completed in 1824. The distance between the points of support is 422 feet 3 inches; the deflection of the chains 29 feet 3 inches; and the tension on the iron at the points of suspension is 1·857 times the entire weight suspended. The piers are of stone, 22 feet thick, 46 feet wide at the top, and 72 feet at the water-line, and their height above the level of the road is 48 feet; through each pier is an arched opening 14 feet wide. The platform is divided into a carriage-way 20 feet in width, with a footpath on each side 5 feet wide. There are eight main chains arranged in four double lines, viz. two small chains, one under the other on the outside of each footpath, and two large ones on each side of the carriage-way. The small chains each contain three lines of bars 8 feet 10 inches long from centre to centre of the eyes, 5 inches broad, and 1 inch thick. They are united by screw-bolts 2¾ inches in diameter, and coupling plates 15¼ inches long, 8 inches broad, and 1 inch thick. The large chains contain six lines of bars, of the same dimension as those described; all the chains pass through openings in the main piers, and over rollers and iron carriages, each of which carries two sets of rollers one under the other. From the piers the chains or backstays pass down at the same angle as the chains of the central opening. The abutments are in length 45 feet, in width 40 feet, and 15 feet deep, and the weight of each is computed at 2160 tons. The chains are carried through tunnels 2 feet wide, where the smaller enter the abutments, and 3 feet for the larger chains. The chains are secured to strong holding-plates, which are bedded in the brickwork, and are all of hammered iron; the vertical rods, 1 inch square and 5 feet apart, are attached to the coupling plates of the main chains by

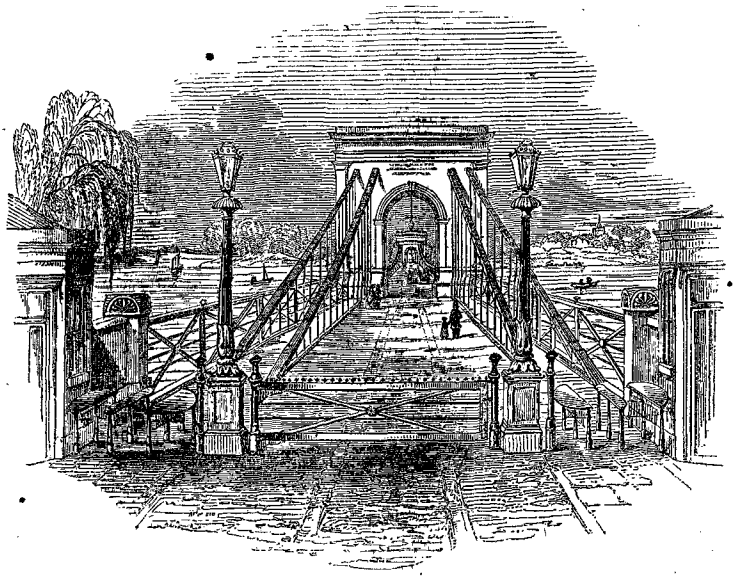


Fig. 528. HAMMERSMITH SUSPENSION BRIDGE.

short links and inch-round screw-bolts. The roadway is formed of transverse joists 12 inches by 4, on which longitudinal beams are laid, and then the planking.

Marlow Bridge is nearly similar in its construction; its total length is 426 feet, and the carriage-way is 20 feet broad, the height of the platform is 12 feet above the water; there are four main chains composed of flat bars; the deflection is 18½ feet, and the section of the iron in the chains altogether is 64 square inches.

Norfolk Bridge, at New Shoreham in Sussex, is another beautiful suspension bridge by the same engineer. The chord line between the piers is 284 feet, and the deflection of the chains 20 feet 2 inches; the breadth of the platform within the parapets is 28 feet 6 inches, the width of the carriage-way being 20 feet. There are on each side three lines of chains, the sectional area of the whole being 84 square inches. The bars are 8 feet 10½ inches long, 6¼ broad, and 1⅛ inches thick, with eyes 8¾ inches in breadth; where the chains are suspended are rollers of cast-iron, all 10½ inches in diameter, with 2⅜ wrought-iron pivots.

There is a central arched opening through the main piers, and the abutments, which are solid, weigh 900 tons; the backstays are not put at the same angle as the central chains; the platform of timber is in length 268 feet, and the total weight suspended in the central opening is about 356 tons, or at the rate of 62 pounds per square foot.

Micklewood Bridge, designed by Mr. James Smith of Doune, differs in its construction from most others; the platform is not suspended, but supported upon iron frames, which rest upon the chains. The span is 103 feet, and there are two supporting chains on each side about 2⅜ inches in diameter, and 1 foot apart, which are fastened to iron frames. The joists which support the platform rest upon iron uprights, set on the chains, the lower ends being made like a fork to embrace them. There are twenty cross joints, the scantling of which is 12 inches by 5, and the whole is cross-braced and secured.

Broughton, near Manchester; this suspension bridge has 145 feet 6 inches span, with a deflection of 12 feet 6 inches; the platform is 18 feet 3 inches wide, and 143 feet 3 inches in length; it is supported by four chains, two on each side, formed of rods 2 inches in diameter, and 4 feet 6 inches long, united by coupling links of inch-square iron and pins 2 inches in diameter. The vertical suspension rods, 1 inch in diameter, spread out at top like a fork, where they are pinned to an iron plate.

The main chains are supported by four cast-iron suspension frames, each carrying a pair of chains, and the points of suspension are movable to allow for contraction.

Suspension Bridge over the Avon at Twerton, near Bath, is in length 230 feet, and the width of the roadway 14 feet; it was executed under the direction of Thomas Motley. There are two pair of pyramids, placed on a bed of concrete, 22 feet by 12, and formed of six courses of Bath stone 30 inches deep, having two blocks on each course; the dimensions of the pyramids at their base is 5 feet 6 inches by 4 feet 6 inches, and at top

3 feet by 2 feet 6 inches. The distance or span of the middle compartment is 120 feet from centre to centre, and between them and the land 55 feet at each end. At the base of each pyramid, level with the roadway, is a cast-iron bed, secured by iron bolts inserted into other iron plates worked in the foundation; an iron bar, 3 inches by 1 inch, passes through the centre of the pyramids into a cast-iron plate at the top.

The suspending bars average 2 inches by 1 inch, and are placed 2 feet 6 inches apart; these are fastened by gibes and keys into a cast-iron plate, which passes up the side of the pyramid from the base to the top. The main beam is formed of two wrought-iron bars, 7 inches by $\frac{5}{8}$ of an inch, arranged in lengths of 18 feet, breaking joint, and connected by brace plates. At the edge of each suspending bar an upright piece of iron, about 12 inches long, is welded, to which the upright supports are attached; in these uprights are eyes through which the suspending bars, which are all arranged parallel, pass, and are made tight by wedges above and below the bar. These suspending bars are attached to a round bolt 2 inches in diameter, which passes transversely, and connects the two ribs or beams. At the abutments the ribs are secured by cast-iron bolts and plates. The weight of the suspending and upright bars is 7 tons, and the total quantity of wrought-iron is 18 tons, and of cast-iron 5 tons. The floor is of Memel joists and oak platform, and the cost was 2500*l*. As there are twenty-four suspending bars, whose united sections equal 48 inches, and one inch will support 20 tons, this bridge would carry 960 tons, but as the leverage is as 4 to 1, we must only allow one quarter, including the weight of the materials.

Turning or Swing Bridges.—There have been a great variety constructed over the various canals and dock entrances: among the best in design are those at the West India Docks.

The roadway is carried upon cast-iron plates, which are secured to the ribs by iron bolts and nuts, the ribs being cast with flanches to receive them.

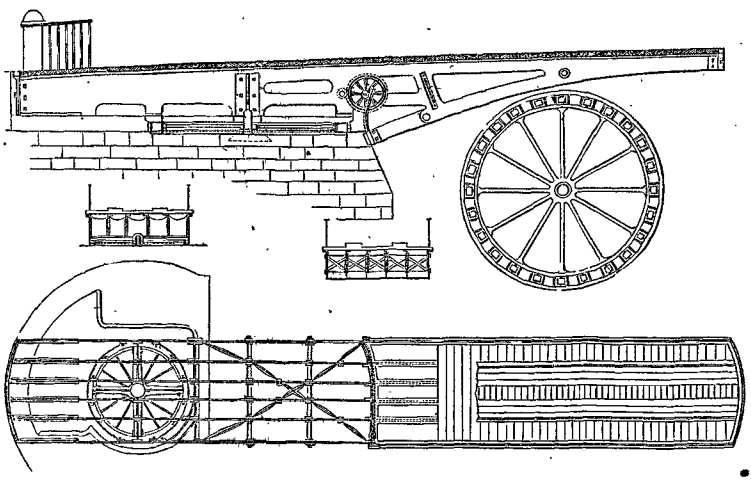
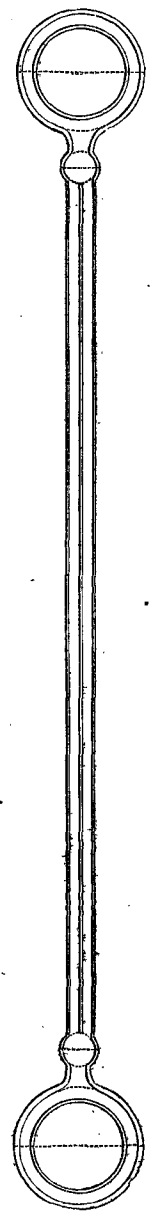


Fig. 529. ST. CATHERINE'S DOCK SWING BRIDGE.

At St. Catherine's Docks the bridge is equally divided in its length, one half being made to swing each way, the tails working round three parts of a circle; the clear opening between the walls being 44 feet 9 inches, and the rise in the middle 3 feet 8 inches. The turning is effected by a wheel working horizontally on a number of rollers that run upon a bed of cast-iron, and so nicely is the whole balanced, that by means of a rack and pinion it is easily worked. Iron bridges of this kind are generally adopted in preference to those of timber, which were formerly used; although more costly in the first instance, there is greater economy in the end, and from the superior quality of the machinery applied, and the nice adaptation of the parts, and perfect balance maintained, there is little labour required to open and shut them. On canals in particular where a single lock-keeper or attendant is on duty, it becomes indispensable to provide the means of turning a bridge with the least possible labour, and to so great perfection have our engineers brought the construction of these swing bridges, that they may be manœuvred almost by a child. The ribs, when rightly proportioned and put together, are calculated to bear any weight they may be subjected to, and, when properly balanced at their turning end, there is no danger of their getting out of order, or sagging.

The Thames Tunnel. — Having described some of the stone, iron, and suspension bridges constructed over the rivers of Great Britain, our attention is drawn to a method of passing under the current, so as not to interrupt navigation: this has been accomplished by Sir Mark Isambard Brunel, a native of France, after sixteen years' constant labour and attention; the Thames having broken in upon the work three several times.

Before it was commenced, and as early as the year 1798, Mr. Dodd proposed a communication between Gravesend and the Essex coast by a passage under the Thames; another at Rotherhithe was projected by Mr. Chapman in 1804, and three years afterwards a shaft, 11 feet in diameter, was sunk at a distance of 315 feet from the river. Mr. Trevithick, who thoroughly understood the difficulties of such an undertaking, was then engaged to drive a way under the navigable part of the Thames, and after great labour he formed a drift way, 5 feet in height, 2 feet 6 inches in breadth at top, and 3 feet at bottom, for a distance of 1046 feet under the river. Early in the year 1808 the water broke in upon the workmen, although there was at least a thickness of 25 feet between them and the bed of the river; this, perhaps, might have been prevented, if precautions had been taken to line the way with brick as the work proceeded. After this event a company was formed to carry out the plans which were projected by Mr. Brunel in 1823: a shaft was afterwards sunk, by first driving 24 piles, with a shoulder projecting on the side of each, within the circle intended to receive it; on these was laid the timber curb, which also partly rested on one of iron; 48 wrought-iron bolts, 2 inches in diameter, passed upwards through this to a height of 40 feet, or to the top of the intended shaft. The curb or rather tower was built upon it with bricks laid in cement, and as the work proceeded it was bound together by 26 circular timber hoops $\frac{1}{2}$ inch thick: when the brickwork was completed, on the top was placed another wooden curb, through which the long iron bolts passed, and their ends being formed into screws, the whole was by nuts held in one entire mass. The construction of this brick curb was completed in three weeks, and in seven or eight days, when the cement had hardened, 16 of the piles on which it rested were driven by pairs opposite to each other, $\frac{1}{2}$ inch at a time, and then the whole gradually sunk, carrying with it the other 8 piles; after this effect was produced, the 16 piles were drawn out by opening the ground at the back; the whole weight of the brick shaft, which was 910 tons, then rested on the 8 piles, and these were eventually drawn, when a bed of gravel was arrived at for a foundation. Mr. Brunel commenced this work on the 1st of January, 1826, and by the 27th of April in the following year 540 feet of the tunnel were completed. On the 18th of May the river broke in and filled it. After this irruption only 50 feet was advanced in 1827, when, upon a second irruption, the work was totally abandoned. In 1835 the government made some advances of money, and a new shield was provided, a masterpiece of ingenuity and contrivance, executed by Messrs. Rennie, which was fixed March, 1836; the work was resumed and continued until the 11th of June, when the water again broke in, and retarded any further progress for six weeks; after which it was continued until completed, in 1842, without any serious interruptions.



PLAN OF THE THAMES TUNNEL.

Fig. 530.

There is a double tunnel throughout the whole distance between the shores of Rotherhithe and Wapping, through a *blue tenacious clay*. On the Rotherhithe side, at 150 feet from the river, is a shaft 50 feet in diameter, 42 feet in height, and 3 feet in thickness; this was built on the surface, and the ground excavated afterwards, the earth and water being drawn out at the top by means of a steam-engine. It was sunk in its place bodily, and passed through a bed of gravel and sand 26 feet deep, causing great difficulty in the first attempts: when this 50 feet shaft had descended 65 feet, it was followed by another from the lower level, of 25 feet diameter, which was carried down 80 feet for the purpose of effectually draining the works.

The tunnel was commenced at a depth of 63 feet, with a fall of 2 feet 3 inches in every 100 feet. The part excavated was 38 feet in width, and 22 feet 6 inches in height, having a sectional area of 850 feet; the bottom at the deepest part of the river was laid 76 feet below high water. The excavation was carried on by means of the shield, which was

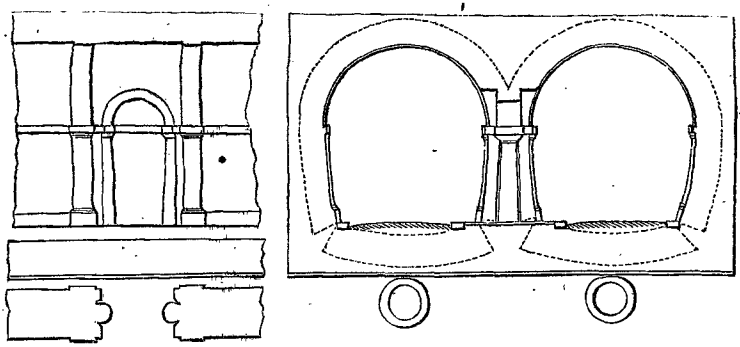


Fig. 531. THAMES TUNNEL.

composed of twelve frames close together, each having three cells, one above the other, in which the miners worked. As the work advanced, polling boards were pressed firm against the earth by means of screws, and closed the whole area of the excavation in front: this shield weighed 180 tons; the mass of earth removed was 63,000 tons; the weight of the brickwork 26,160 tons, and it is stated that the cost was not less than 1200*l.* for every yard advanced.

Roads. — The Romans intersected Great Britain with roads, set out in straight lines from one city to another, and from their military stations and camps to the coast; they were often paved, and remained for centuries in the best possible condition, and were the principal media of communication. Some of the great lines may be traced, as may the remains of the sepulchres at their margins, containing coins, vases, ornaments of the dress, and arms. The name of street is still applied to them, particularly the chief, as Watling, Ikeneld, and Ermine.

The Roman roads were, however, narrow, and as manufactures were introduced, and a consequent increase of traffic took place, we find a desire to improve these means of communication.

In the year 1285 the owners of lands were enjoined to widen the roads, by cutting down trees on each side to a certain width; in 1346 a law was passed to levy a toll on some leading out of London, which were reported to be impassable. In the reign of Henry VIII. laws were enacted binding the several parishes to take care of the roads, and annually to select qualified persons to superintend them: but simple as are the principles of road-making, those appointed are seldom sufficiently instructed on the subject, and being rate-payers are too much interested to allow of the requisite outlay, thus many of the parish roads are in a wretched condition, the system adopted by most parish surveyors being merely to fill up the ruts and inequalities with stones picked from the surface of the land, or gravel dug in some convenient spot: this operation, repeated in the spring and autumn, constitutes their whole duty; no attention being paid to the nature of the soil, or the selection of the material that will bind with it to form a hard exterior crust.

Stage-coach travelling had certainly arisen to a very great perfection before railroads were introduced; the carriages were easy, well-constructed, and drawn by a superior breed of horses. Considerable capital had been employed in the improvement of the turnpike roads; hills were levelled or cut through, valleys filled up, and as straight a line as possible was obtained; their repair was never neglected for an instant; immediately any part of the crust was broken or worn away, it was the signal for a general spreading of fresh material; the smooth surface of the road being previously broken up into furrows to a depth of 2 or 3 inches; this process, called *lifting*, was followed by spreading the stones 3 or 4 inches deep, and raking them even until the whole was consolidated into one entire mass.

The same system should be adopted by the superintendents of all parish roads; an engineer or director should be set over a district or county to see justice done to the public, and to instruct those who are too generally incompetent to perform the duties imposed upon them.

The footways or paths that lead from one village or town to another, equally important to public convenience, and which hitherto have never been repaired, deserve to be scrupulously regarded and maintained in the best possible condition: no proprietor should be allowed to divert them out of a direct line, and the straightest course should be taken.

Towns, Streets of. — In all large towns it has been found advisable to pave the streets and footways, and in consequence laws have been established to regulate the expenses, and to elect persons competent to collect and disburse the necessary funds; various local acts were obtained before the passing of one (which comprised nearly all the measures then deemed requisite) in the year 1817 (57 Geo. 3. c. 29.), which contains provisions for the

guidance of the authorities with respect to the convenience, safety, and cleanliness of the towns.

The corporation of the city of London appoint their own commissioners, and Westminster and the other parishes within the bills of mortality are under the jurisdiction of local commissioners or their vestries.

All inhabited houses and shops are rated according to the value at which they are assessed for the poor-rate to provide funds for the purposes of paving, &c.; and public buildings pay a shilling per square yard over half the public way in front or belonging to them.

The commissioners of paving regulate the duties of the scavengers and dustmen, levy fines for the deposit of rubbish of any kind, either on the footways or streets, and are empowered to cleanse the public thoroughfares, to contract for the watering of the streets, and provide all that is requisite for the purpose; for which the inhabitants deriving the advantage pay a tax not exceeding one-fortieth part of the rental. When new streets are formed, or old ones improved, the commissioners may purchase the ground necessary, or call a jury (stat. 3 Geo. 1. c. 25.) for fixing the value.

Parish Roads.—All that was excellent in the old statutes, or authorized by custom for the regulations of parochial roads, was embodied in an act passed in 1773 (15 Geo. 3. c. 78.), under which a surveyor is annually chosen, whose duty it is to maintain the roads of his parish in good order. The act states that on the 2d of September every year, or the Monday following if it should fall on a Sunday, a meeting for the nomination of ten candidates for the situation of surveyor shall take place; they must possess property or income to the annual amount of 100*l.*, or be occupiers of land or houses of the yearly value of 30*l.* Three days after the meeting the constable presents the list to a justice of the peace, and it is subsequently laid before a Special Quarter Sessions held the first week in October. The justices then appoint one or more surveyors of roads for each parish; should the candidates appear to them incompetent, they have the privilege of electing a respectable house or leaseholder who may not be included in the original list.

A surveyor so chosen manages all the executive part as well as the expenditure, for which he is personally responsible, and his office is somewhat similar to the ædile of ancient Rome, his only reward being the exact performance of his duty; but a professional surveyor may be appointed with a salary if the parish, or more than two-thirds of those qualified to vote, agree. Surveyors chosen from among the parishioners often exhibit great zeal, and some knowledge of their subject; but the professional man, who devotes his life to the practice of such works, must be better qualified for the task, and his attention will necessarily be more concentrated upon it, and were such offices filled by persons selected for their knowledge as civil engineers, there can be little doubt that, with perfect integrity, the highways in each parish would be maintained at a cheaper rate and in better order. The magistrates of each county might have the power to nominate an engineer-in-chief, or an officer from whom some general instructions should proceed.

Laws relative to Public Roads.—By the act 13 Geo. 3. c. 78. s. 63., it is deemed unlawful to dig a ditch, plant a hedge, trees, or shrubs, or fix a paling within at least 15 feet from the centre of the road. The ditches and drains on each side are to be maintained and kept in repair by the owners of the adjoining ground. They must also make the bridges or lay the pipes where the communications take place with their property. The surveyors may procure gravel, sand, chalk, or stone from the commons, and from every river or stream throughout the parish, but he is restricted from injuring any private or public buildings.

Turnpike Roads were established after the return of Charles II., and acts were passed in the second year of his reign for widening and repairing some of the public roads: the first relates to that from London to Scotland, which passed through Hertford, Cambridge, and Huntingdon. Many subsequent acts followed, but all the important laws were combined in the 13 Geo. 3. c. 84., which was again modified by the 3 Geo. 4. c. 126., containing all the regulations requisite for this important subject; it arranges the collection of the road tax, and places the receipt and employment of the funds under the direction of trustees: a trustee must have an income of 100*l.* per annum arising from landed property, or be presumptive heir to some one having an income of double that amount; and within ten miles of London the qualification is 10,000*l.* personal property after the payment of all debts.

The revenue arising from the tolls is paid into the hands of a treasurer by the receivers, who are to present their accounts to the trustees whenever called upon, but always at their annual meetings, which are held for the express purpose of examining and passing accounts; besides this there are as many special meetings called as may be deemed necessary, three members being sufficient for ordinary purposes, and seven to alter or revoke an order made by a preceding assembly. The trustees have the power of shortening, improving, or altering the direction of a road; but they may not deviate more than 100 yards from the old line without consent of the proprietor of the land crossed by the new line. They may borrow the money necessary for making, repairing, or improving the roads, the interest and capital being paid out of the tolls.

The act for each trust limits the rate of the tolls and the number of turnpikes; the trustees having the power of diminishing the toll with the consent of the creditors of the road, and, also, of letting it out by public auction, after having stated by advertisement the net produce during the preceding year. On the erection of a new turnpike the trustees, on proper notice, decide in what situation it shall be placed. All the works for the support of toll roads are under the direction of surveyors appointed by the trustees, as are also the treasurer and other officers. The surveyor has the right, after having obtained the authority of a justice of the peace, to collect in any field stones necessary for his purpose, but he is also bound to pay for the same. The trustees order the fixing of all milestones, finger-posts, and railings in dangerous places, and may prosecute any individual who wilfully damages them.

In the year 1819 it was suggested to the Committee of Inquiry into the State of the Public Roads, that the whole should be placed under the management of government; but, upon the ground that this was contrary to the public interest, the idea was abandoned, and the construction and maintenance of all parish roads are still left to the parish authorities, and those of turnpike roads to the various trustees, the government alone interfering when improvements essential to the general prosperity, and which are too costly for the local districts, are to be carried out.

The narrowest limits which the law permits to be given to by-roads are as follows:— footpaths 6½ feet, horse-roads 8 feet, and carriage-roads 20 feet; their width may be increased to 30 feet, viz. 16 feet 6 inches for the horse-road, and the rest given to the footways and ditches.

The width of turnpike roads, determined by act of parliament, is 60 feet for the approaches to populous towns, though in many places this is reduced to less than 20 feet.

The total length of the paved streets and turnpike roads in England and Wales, as reported by the Committee of the House of Lords in 1829, was 19,798 miles, and that of the cross-roads and other highways 95,000 miles.

It is curious to refer to the progress made in turnpike legislation, which may be thus stated: from 1700 to 1710, twelve turnpike acts were passed; from 1710 to 1720, twenty-one; from 1720 to 1730, seventy-one; from 1730 to 1740, thirty-one; from 1740 to 1750, twenty-nine; from 1750 to 1760, one hundred and eighty-five; from 1760 to 1770, one hundred and seventy-five, making up to this period five hundred and thirty acts of parliament which had received the royal assent. These acts were limited to a duration of twenty-one years, as it was presumed that at the end of that period the tolls imposed would not be required: the clerks of the several trusts always take care, however, that some creditors of the road should remain unpaid, by which means they contrive to keep the trust alive, and prevent their own office becoming extinct. The renewal of the Turnpike Act is also profitable to the clerk, and since 1830 the term has been prolonged to thirty-one years; at present the trusts in existence exceed 1100.

The General Turnpike Act now in force, the 3 Geo. 4. c. 126., was passed in the year 1822.

By a statement made to Parliament of the income and expenditure of the 1111 trusts of England and Wales from the 1st of January, 1835, to 31st of December, 1835, it appears that the

	£
Bonded mortgage debt was	7,116,702
Revenue received from tolls	1,469,317
Money borrowed on security of tolls	165,474
Manual labour	397,665
Farm labour	134,861
Materials for surface repairs	215,835
Interest of debt	301,508
Improvements	211,808
Debt paid off	132,983

Wherever the government has undertaken the formation of roads, engineers have been appointed to make a careful survey of the country, and take the levels of the line to be set out; and some of the best roads in the world have been the result of this arrangement; those in Scotland, the Glasgow and Carlisle, and the Holyhead, which were made under the able superintendence of Mr. Telford, may be enumerated as examples. A brief account of the methods adopted may give an idea of the great care bestowed upon them by that eminent engineer.

The Highland Roads and Bridges, executed under the direction of Mr. Telford, by the aid of parliamentary grants, constitute so great an improvement, that they deserve our particular attention; the whole were completed in a short space of time, when the work done and money expended are considered.

As the Highland road was chiefly for the accommodation of cattle, hard substances

were rejected; they were often formed along steep hill-sides and rocky precipices, and are always sufficiently wide to admit of two carts passing. Wherever the land-owners required a road, an application was made to the parliamentary commissioners, accompanied by the offer of defraying half the expenses; the district was then surveyed, and the cost estimated, after which the memorialists were called upon to deposit half the amount in the Bank of Scotland; detailed working drawings and specifications were prepared, and the ground marked out, and contractors were found to undertake the work under proper surveyors. Where the length of road did not exceed ten miles, it was generally contracted for by one person, but it was frequently divided among many, separate tenders being given for different lots. The general superintendent and special inspector were appointed by the chief engineer, Mr. Telford, to whom the inspector made a regular monthly statement, which was afterwards sent to the commissioners.

When the roads were completed, those who contributed the moiety of the expense were invited to survey them, and to join in the certificate that the whole was executed agreeably to the contract and specification, after which the last eighth of the total sum retained was paid to the contractors.

There were 920 miles of new road, and 1117 bridges, built in the course of 18 years, under 120 contracts, without recourse being had to a court of law in any one instance.

Many of these roads were originally mere tracks, and it was sometimes necessary to carry the lime for making the mortar in sacks on the backs of horses for upwards of twenty miles. The stones for the arches of the bridges were brought by sea, many districts not affording sufficient to cover a drain 2 feet in width.

The setting out these roads, and constructing the bridges throughout the most unfrequented parts of Scotland, called into practice a new class of engineers, hitherto unknown, who soon systematised the labours they had to perform, and introduced a nomenclature and method by which others could direct similar operations. An evident improvement took place on all our mail-coach roads, which was imitated by those who had the charge of other trusts. Material was sought for where it could be most easily obtained, and experiments were tried upon its quality before contracts were entered into for its employment; many surveyors, who were before incompetent to judge of the quality of the metal with which they formed the crust of a road, turned their attention to its chemical and mechanical properties. Small, smooth, round pebbles were no longer heaped together to be spread over the middle of the carriage-way, but limestone or granite broken into angular masses was carefully laid over the whole to one uniform depth. Every precaution was taken for draining and keeping the road clean; the manner in which these operations were carried out cannot be better understood than by referring to the following instructions drawn up by Mr. Telford, which may be serviceable to those who have similar works to perform, and as there is now every probability of railroads becoming general, it is peculiarly necessary to preserve documents which relate to so direct an evidence of our progress in civilisation.

"*General specification for the Highland Roads.*—The road to be formed to the full breadth of 20 feet in the clear, including the side drain and green margin, except on places where there is an absolute necessity for cutting the whole breadth of the road in solid rock; and in those places the breadth of the road shall be 18 in the clear, between the parapets which may be necessary for a safeguard, and those parapets are to be 2 feet in thickness at the bottom, so that in rock the cutting will be 20 feet in breadth, and in all cases the road is to be so laid out, that there shall be no quick bendings, nor its upper side interrupted by points of rock.

"On dry bottomed ground, gravel of a proper quality, out of which all stones, above the size of a hen's egg, shall have been previously taken, shall be laid to the depth of 14 inches in the middle, and 9 inches at the sides; but the stones which are taken out of the gravel, and do not exceed 4 inches in size, may be laid for that thickness below the gravel, and in that case 10 inches only of cleansed gravel will be required.

"On mossy ground or swampy soils, if the moss or soft matter is not more than 2 feet in thickness, and a hard bottom below this moss or soft matter, it is to be wholly removed,

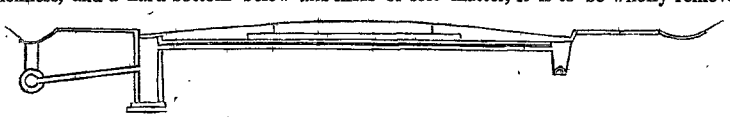


Fig. 532. SECTION ACROSS ROAD.

and the road formed on the harder substance as above described; but when the moss or soft matter is more than 2 feet in depth, the contractors are to have their option of either removing it, or forming the road upon the top of it in the following manner.

"Where the surface is level, and covered with sound sward or heath, there must be laid two rows of swarded turf, with the swarded side of the one downwards, and of the other

which is to receive the gravel upwards; or otherwise, where turf cannot be readily procured, the surface of the moss or soft matter may be covered with a layer of brushwood or heath, which, when compressed, shall not be less than 6 inches in thickness; upon the surface so compressed and prepared, there shall be laid gravel, cleansed as before described, to the thickness of 18 inches in the middle and 13 inches at the sides.

"In all cases, whatever be the nature of the soil, the road is on all the flat ground to be brought to a perfect level from side to side, before the gravel is laid on; but in all cases where the road is to be raised on the one side by moved ground, while the upper side is on the natural ground, the lower side of the road, when finished, is to be from 4 to 6 inches higher than the upper side, in proportion to the quantity of moved ground on the lower side.

"In side cuttings in steep banks, even if there is no moved ground on the lower side, still the lower surface of the finished road is to be on at least 4 inches higher level than the upper side. Where the ground is level or flat, the road is to be gravelled to 18 feet in width, and to have a border of green turf on each side, 1 foot in width.

"When the road is formed on a sloping bank, where no parapets are necessary, there is to be a border of green turf on the lower side of the road, 1 foot in breadth in the clear.

"The drains are to be formed perfectly regular, and so as the course of the water shall not be interrupted by points of rocks or sudden turnings, and where the soil is soft and loose, these drains on the upper side of the road are to be paved with small stones, not less than 4 inches in depth. These pavements are to be made at the places pointed out by the inspector; they are to be carried to the extent, and made in the shape, he shall direct.

"Where the parapets are necessary, the road is to be gravelled to the breadth of 18 feet as before described. And also the said contractors bind themselves and their foresaids to make in a sufficient manner all back drains, of such dimensions, and in such directions, as shall be necessary for effectually collecting and conducting the water in a proper manner from the higher grounds to the nearest bridges or covered drains, especially where the road is formed along steep and sloping banks, and the ground is wet and swampy, and that at the places which shall be pointed out by the said surveyor, so that the road shall always be kept free from water.

"Where the road is to be formed upon level ground, and particularly where it is mossy and swampy, side drains are to be made of sufficient depth to drain the ground; and in all cases quite sufficient to carry off the water. These side drains to be made with a slope from the road to within 1 foot of the farther side of the drain, so that if the depth at the farther side be 30 inches, the width at top shall be 6 feet, and so more or less in proportion to the depth, and which side drains shall be made at the places approved of by the surveyors: and also to make covered drains of dry stones at all places were necessary; the inside walls of these drains are not to be less than 2 feet in thickness, and the stones for that length to be laid regular: these covered drains shall in no instance (without particular directions in writing from the principal engineer employed by the commissioners) be less than 2 feet square; they are to be properly secured in the bottom by paving with stones set on edge; the pavement as well as the sides are to be secured at both ends of the drains by stone work, so that it shall appear evident there is no risk that they shall be injured by the water, where it enters into or issues from the drain. The stones with which the two feet drains are covered are to be not less than 3 feet in length and 4 inches in thickness, and laid so close together on stones of equal length overlapping each joint, as shall effectually prevent the gravel from passing down into the drain, and leaving a hole in the road. But in case it shall be discovered during the execution of the road, that instead of some of the 2 feet, the road may be better protected by making a greater number of drains of smaller dimensions, the contractors, upon receiving instructions in writing from the principal engineer, shall execute them in such a manner, and counting two drains of 18 inches, or three drains of 12 inches, in lieu of one drain 2 feet square, and in case of drains of 18 inches being made, the stones of the covers shall not be less than 30 inches in length; if 12 inches the covers to be 2 feet in length; and in order to secure the due execution of the said covered drains, it is expressly declared that the same shall be subjected to the inspection and approval of the resident surveyor before the covers are laid on, that he may be satisfied that the bottoms are properly paved, and the sides are built in a sufficient manner; and after the said drains are covered, the backs of the buildings are to made up with stones to the level of the upper beds of the covers, and the said drains shall be constructed, so that they shall have a sufficient covering of gravel, not exceeding 12 inches, to the satisfaction of the surveyor, without causing any swell on the road. And also the said contractors bind and oblige themselves, and their foresaids, to build and erect breastworks of stone at all places where necessary on the lower side of the road, along the side of watercourses, or on sloping banks, or on rocks; the foundation of the said breastwork must be cut into the rock or solid ground for the whole breadth of the base of the wall or breastwork which is to be placed on it, as hereafter described, and its direction is to be dipping into the hill at a right angle with the slope of the face of the breastwork. If it shall be necessary to make the breastwork 3 feet in height, from the foundation to the level of the

lower side of the road, the breadth of the foundation shall be 24 inches, and 18 inches at the top, or level of the lower side of the road. If the height is 4 feet, the breadth of the foundation is to be 30 inches, and at the top 24 inches. If the height is 6 feet, the breadth at the foundation is to be 3 feet, and 2 feet at the top. If the height is 8 feet, the breadth of the foundation is to be 4 feet, and at the top 2 feet, and so on in proportion to any greater or lesser height. In forming these breastworks, the stones are to be laid in regular manner, quite through the thickness here described; the slope which is necessary to bring the wall to its thickness at the top is all to be taken off the outside, and the stones are to be laid mostly lengthwise into the wall; the space behind the breastwork and natural ground, up to the level of the top of the formed roadway, is to be filled up with coarse gravel or stones, (neither sand, sods, nor moss, to be used,) and if with stones they are to be covered and brought to the levels formerly described, with a layer of strong swarded turf, before the cleansed gravel is laid on.

"At all times, when the nature of the cutting makes it possible, the resident overseer shall have an opportunity of examining the breastwork when completed, before the inner side shall be filled up with stones or gravel as aforesaid, and also, where it shall be necessary for the due execution of the said road, to erect parapet walls above breastworks, or upon rock, they are to be built with stones laid in good lime mortar, agreeably to the ground report.

"These parapets are to be 2 feet wide at the foundation, and 18 inches at the top. The height above the finished roadway is to be 2 feet 9 inches, including a coping of stones 9 inches deep. These coping stones are to be chosen, so as to meet one another in close regular beds or upright joints, to be firmly wedged together, and pointed with lime mortar.

"At each extremity of the parapets the copings are to be well secured with the ends turned down under the roadway, and also where it shall be necessary in forming the road, to cut and remove earth from the higher side, to the depth of 2 feet or more, the road must be formed 21 feet 6 inches wide, and, to prevent the earth from falling into the drain on the upper side of the road, a wall of dry stones must be erected of a height according to the depth of the cut. The foundation of those retaining walls is to be laid in all cases 6 inches below the bottom of the drain, on the upper side of the road; there the thickness is to be from *15 to* 18 inches to the height of 4 feet; above that height they are to be $\frac{1}{8}$ of the thickness. The stones with which they are constructed are to be laid in a regular and workmanlike manner for the whole thickness of the wall; they are to be carried to such a height, that the slope from them to the solid ground of the bank above is not to be less than two horizontal to one perpendicular, and that slope to be covered with turf laid flat.

"And further, the contractors are to be bound to cut down all heights, fill up all hollows, and blast all rocks upon the said line of roads, as pointed out by the said reports, and which shall be requisite and necessary for the same: and further the said line of road shall be formed and prepared for the gravel for one mile at least per advance to the satisfaction of the surveyor employed by the said commissioners before any of the cleansed gravel is laid on."

Every necessary precaution was taken to render these roads efficient, and where the foundations were of a soft nature, concrete was spread entirely over the surface, made with hard stone, or gravel mixed with lime in the proportion of one of the latter to four of the former; and the greatest care was used, when the water was added, that the lime was properly slaked and saturated. The depth of the bed of concrete varied according to circumstances: in some instances, 6 inches was found sufficient, in others more than double that depth was required; and before this became thoroughly set or hard, the broken stone was laid on, in order that it might bed itself, and unite firmly with the upper surface; for it is very important that there should be a junction between the two bodies, otherwise the stones would be in constant motion, and never form a firm and durable crust; by laying the courses of broken stones on at intervals, the roadway is rendered perfectly solid, and in one mass from bottom to top.

Glasgow and Carlisle Road differs materially from those in the Highlands, as it was necessary to provide for the transit of the mail, and heavy coaches and carts carrying 3 or 4 tons; it was made with the utmost care, all the ascents and descents set out with an easy

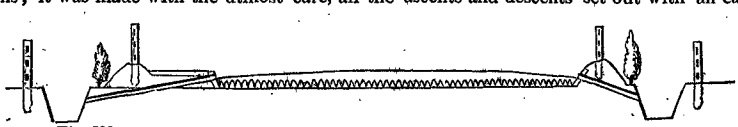


Fig. 533. SECTION OF ROAD.

and regular slope, never exceeding a rise of 1 in 30. These works were directed by Mr. Telford, after the act of parliament was passed in 1816.

The old road, which had become impassable, was in length 102 miles; the present is not more than 93, and in order to gain this 9 miles, it was necessary to reconstruct 69 miles entirely, and to build fifteen new bridges; exclusive of the bridges, the expense of the road-

making was about 1000*l.* per mile. It was specified that the breadth was to be 34 feet between the fences, 18 of which were to be metalled, and the remaining 8 feet on each side to be covered with gravel. In all embankments the width on the top to be 30 feet, and the side slopes 1½ horizontal to 1 perpendicular; in all cuttings above 5 feet, the width between the lower skirts of the slopes 30 feet, all below that depth to be 34 feet. The slopes of all the cuttings to be at the same rates as the embankments.

The surface of the road longitudinally or lengthwise, in all cases where there were cuttings and embankments, to be formed as shown, and in no instances the ascents or descents to exceed 1 in 30, and the changes from one to the other to be made in regular curves, to the satisfaction of the inspector.

Where there were side cuttings and a part of the road made on moved ground, the surface of the lower part, or moved ground, to be higher than that of the upper side, to allow for consolidation, so that when finished it might have the proper level.

In the middle of the road a metal bed to be formed, and in all cases where the ground was nearly level, the metal to be laid upon the natural surface of the ground, so as to have a curvature of 4 inches, in the middle 18 feet, and the sides or shouldering to be made with moved ground, but on no account the metal bed to be cut out of the natural ground, unless that be loose gravel or rock.

The metalling to consist of two beds or layers, viz. a bottom course of stones, each 7 inches in depth, to be carefully set by hand, with broadest end downwards, all cross-bonded or jointed, and no stone to be more than 3 inches wide on the top. These stones to be either good whinstone, limestone, or hard freestone; the vacuities between to be carefully filled with smaller stones packed by the hand, so as to bring the whole to an even and firm surface.

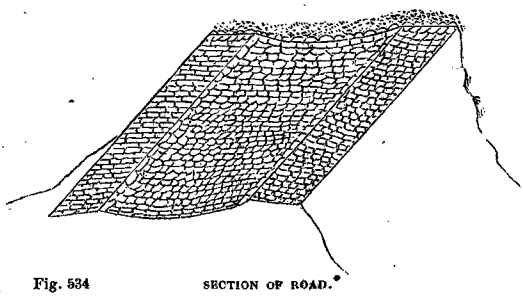
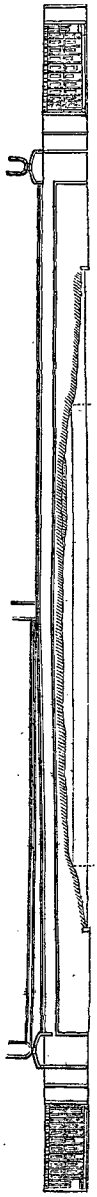


Fig. 534 SECTION OF ROAD.

The top course or bed to be 7 inches in depth, to consist of properly broken stones, none to exceed 6 ounces in weight, and each to pass through a circular ring 2½ inches in diameter in their largest dimensions. These to be of hard whinstone, the quality of both bottom and top metal to be determined by the inspector. In every 100 yards in length on each side of the road, upon an average, there was to be a small drain from the bed of the bottom layer to the outside ditch, as directed by the inspector.

Where the height of the embankments exceeded 3 feet, they were to stand from one to three months, in proportion as they increased in depth, as determined by the inspector. Over the upper bed or course of metal to be a binding of gravel, of 1 inch in thickness upon an average; the cross section of the finished roadway to have a curvature of 6 inches; in the middle 18 feet, and from that on each side a declivity at the rate of ½ an inch in a foot, to within 18 inches of the fences; the remaining space of 18 inches to have a curvature of 3 inches, making in all about 9 inches on each side below the finished roadway.



TRANSVERSE SECTION OF ROAD.

Fig. 535.

In passing morassy ground all the surface upon which the road was to be placed, viz. between the fences, to be brought to a curvature of 12 inches in the middle, and to be secured with two rows of good swarded turf, the lower end to be laid with the swarded side downwards, and the upper one with it upwards. The metalling upon the said mossy ground to be made 20 feet in width; a drain to be cut alongside of the road, 4 feet wide at the top, 18 inches at the bottom, and 3 feet deep.

Cross drains, nine to be made in every mile in length, placed in situations marked out by the inspectors; 18 inches wide, 16 inches high at the upper end, and 22 inches high at

the lower end; their bottoms to be paved with flat or small pebble stones, 4 inches in depth. The foundations of the side walls to be laid at least 6 inches below the level of the bottom of the drain, and these not to be less than 18 inches in thickness, laid in regular courses, faced on both sides, in the manner of a good stone dyke. The top of each to be properly levelled, and covered with a firm turf 2 inches in thickness, to form a bed for the covers. The covers to be 2 feet 6 inches in length, and 4 inches in thickness; their side joints to be made straight, so as to unite closely; the parts which lie on the turf to be flat.

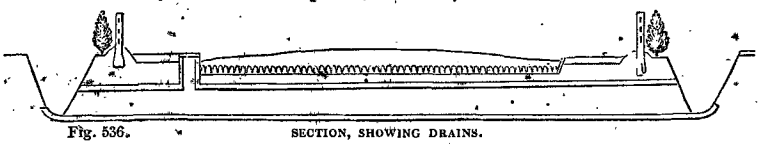


Fig. 536. SECTION, SHOWING DRAINS.

These drains must be of a length, not only to cross the road, but the fences on each side, also the slopes of the embankments, and pass fairly into the fields or natural water-courses; from the ends of the drain, wing-walls to be extended 5 feet in a curved direction into the solid ground, there to be of the same thickness as the side walls, founded at the same depth, and carried to the same height, and coped with two rows of swarded turf. The bottom between the wing-walls to be paved with stones not less than 6 inches in depth, and well secured at the extremities by stones 12 inches in depth, and these to be well secured at the upper ends, and connected with the firm ground and side drains. The whole body of the drain to be at such a depth as to admit of a turf being laid over the covers, and the full quantity of road metal and binding, without raising the longitudinal line of road. At each end of the cross drains, the water which passes along the side of the road to be introduced by a proper opening, protected by a stone cover; this entrance to be paved at least 5 feet in length. In passing through morassy ground, the bottom of the drains to be laid with flat stones quite across, and at least 12 inches under each side wall, to be continued quite to the extremity of the wing-walls.

To keep this road in repair after it was made required at the least 80 cubic yards of broken stone per mile, and at the most 120 per annum; the cost of which varied from 20*l.* to 46*l.* per mile.

Holyhead Road.—The embankment over the Stanley sands near Holyhead is 1300 yards in length, 16 feet in height, and 34 feet in width at the top, including the roadway and parapets.

The slope towards the sea is three horizontal to one perpendicular, and on the other side at the rate of two to one; the breadth at the base is 114 feet; both sides are coated with rubble stone, which has proved an effectual protection against the most violent storms. In one part of the foundation was a hard rock, where an arch was turned which admitted the flood tide to cover the space to the westward of the mound.

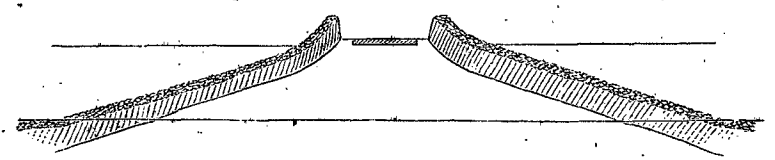


Fig. 537. SECTION OF ROAD.

The embankment for the eastern approach to Conway Bridge is 666 yards in length, and the breadth at the top 30 feet; its greatest height is 54 feet, the slope on the sea-side is 3 horizontal to 1 perpendicular, on the other side 2 to 1; the greatest breadth at the bottom is 300 feet.

The tide flows ten miles above the site of this embankment, and during its construction, the velocity of the current swept away the gravel and earth to the depth of 34 feet, the bottom being hard clay and rock; here a casing of rubble-stone was sunk at the outward extremity of the base on the seaward side, and by persevering in this manner the mound was completed and then protected by a rubble coating.

Railroads have now superseded in a great measure the use of the old turnpike roads, and probably ere long there will not be traffic enough to contribute the toll for their maintenance; we may then anticipate that they will fall into the condition of parish roads, and become again impassable, if the legislature does not provide for the contrary; the next generation will almost require a guide-post at every turning to indicate the route, for few will be found on the way to whom the inquisitive traveller may apply for information, and Pennant's Journey from Chester to London will become as unintelligible as the Itinerary of Antoninus.

Draining and embanking are among the most important operations of the civil engineer; the salubrity of a city or of an extensive district depends in a great measure upon the manner in which its superfluous waters are conducted from the surface, and from the various strata beneath, and we shall find that the laws now in force do not sufficiently bear upon this subject, nor do they respond to the present wants and wishes of the population. When the first regulations were made with regard to sewers, the construction of our houses differed as much as did the habits of those who occupied them; the legal enactments now comprise little more than what refers to the carrying off the water from the surface of the soil, or forming banks to rivers for the purposes of guarding against their overflow. An island like Great Britain requires more than ordinary attention to remove the abundance of moisture condensed upon the surface, and a knowledge of the falls of the several streams, brooks, and other supplies to the rivers which form the arteries of the whole system, is the first thing to be obtained. The rate of motion of water dependent on its fall into the sea, the nature of the soil it runs through, and the length of its course, all require to be studied before any instructions can be given, or a comprehensive plan be arranged for effectually draining any district.

To lay down a map of the whole country, on which should be marked the height of every town and village above the level of the sea, as well as the boundary of every basin drained, would be a great work, but the advantages derived from such a labour would more than compensate for its cost; and if the natural drains, which are the rivers, were shown, with all their tributaries, a comprehensive system might be based upon the knowledge so obtained, and there would be no difficulty in framing laws which would effectually conduce to the general salubrity, and essentially increase the interest both of the proprietors and the cultivators of the soil. Dugdale, in his History of Embanking, tells us that draining a district or a country has a divine origin, "for in the beginning the waters were gathered together, and the dry land appeared, and that after the deluge the waters were dried up from off the earth, and the face of the ground was dry."

All nations seem to have regarded the subject of drainage as one of primary importance, and at a very early period we find it practised in England, but it was principally confined to surface drainage of marshy districts, not forming a part of one grand whole, which is left for the present generation to contrive and carry out.

When sewers are to be made in a city or town distant from the sea, it is requisite to ascertain what will be the result when they unite with the river into which they are to empty, and how the bed of that river is likely to be changed in the course of time by the silting up of the mouth, or by the throwing up of other impediments to its free and natural discharge. To have the sewage of a town under the management of one set of commissioners, and the great trunk into which they are discharged under another, whose object, perhaps, is only to maintain the navigation open, or to construct and keep in repair the banks which confine it, is not likely to work well for the inhabitants of the places so drained.

This is rendered obvious upon examining the state of many of our large and populous towns, situated at the mouths of rivers, which pour their waters into another still larger. The Thames, for instance, receives the Medway, the Darent, and others; and if we look into the condition of the towns on their banks, we shall find that in consequence of the elevation of the beds of these rivers, which at first formed a natural drainage, the whole of the buildings, as well as the surrounding, and once fertile, district, is too often in the midst of a mass of stagnant water and decomposing vegetable matter, producing periodical diseases among the inhabitants.

The streamlets or brooks, which fall into these natural drains, and which once afforded abundant supply of wholesome water, have also become the receptacles of all that is filthy, being converted into common sewers, from the surface of which arise exhalations highly injurious. Never was it more necessary that some comprehensive plan should be laid down to remedy this increasing evil, and to establish some power which should prevent further mischief and bring back the whole to a healthy state of management. This could be readily done if the country were divided into districts, not according to hundreds or parishes, but in reference to their natural position: the whole of the land drained by a river of any importance should be under one controlling power; the valley on each side of the Medway, for instance, or that watered by the Darent, after being accurately surveyed, could have such local laws established as would at once show the necessity of maintaining them inviolable, and that any infringement would be injurious to the interests of all.

The various mills erected on the rivers have all assisted to destroy the effectual draining of the lands on their banks; the outbreaks of the springs have in many instances been penned upon, by creating a head of water, and a whole village has by this means been placed in a morass, its soil, once loose and dry, becoming saturated with water; this is particularly the case on the banks of those rivers where mills and factories have been long established; and we often find the sill, over which the supply to their water-wheels formerly ran, at a depth of 8 or 10 feet below its present level. Now, it must be evident, that had

some control been exercised over this increase in the several falls of water, the natural drainage of the district would have been better maintained. To effect it now, it would be absolutely necessary, in almost every valley in the kingdom, after taking the fall from one end to the other, to open a new channel to carry off those waters that have been deprived of their natural outlets.

Romney Marsh, in Kent, which contains upwards of 24,000 acres of rich land, and which was probably obtained from the sea when the Romans occupied England, is the first district of the drainage of which we have any historical mention. It is defended against the sea by an artificial wall of great strength, extending in length across the opening upwards of 6000 yards, and upon its maintenance depends the efficient drainage of the whole level. There are three grand sluices within it, which allow the fresh water to pass off at the lowest state of the tide.

From Tacitus we learn that the inhabitants of Britain were made to toil in clearing woods, banking fens, and making causeways, and to the Romans we are perhaps indebted for the first regulations upon these subjects; certain it is, that for the conservation of this marsh the first statutes and ordinances were framed, and they formed the basis of all others that were made for the preservation of sea banks and marshes throughout the kingdom. At first, probably, the whole was governed by customary laws, but we find that as early as the forty-first year of King Henry III., these were confirmed; previous to that time the whole management was entrusted to twenty-four jurats, who were appointed by as many townships or manors, and a bailiff named out of their own body, who, like the Saxon reeve, presided over, as well as executed, the powers which were lodged in the whole body. These twenty-four jurats named the quantity of work to be performed by the several owners of the adjoining lands; and, if not promptly attended to, the bailiff took the management into his own hands, and charged the party that had refused, with the sum expended. Henry III., upon some complaints being made, sent his chief justice, Henry de Bathe, to Romney Marsh, to lay down some more efficient laws for the guidance of the jurats than those in operation; and his first ordinances were to this effect:—"That twelve lawful men should be made choice of by the commonalty of the said marsh, viz. six of the fee of the Archbishop of Canterbury and six of the barony, who, being sworn, should measure both the new banks and the old, and those other which ought to be new made, the measure to be, by one and the same perch, *scil.* of 20 feet. And that afterwards the said jurats should likewise, according to the same perch, measure by acres all the lands and tenements which were subject to danger within the said marsh. And all the said measures being so made, that then twenty-four men, first elected by the commonalty and sworn, having respect to the quantity of the banks of those lands, which lay subject to peril, upon their oaths to appoint out every man his share and portion of the same banks, which should so belong to him, and to be made and sustained; so that, according to the proportion of the acres subject to danger, there should be assigned to every man his share of perches; and that the said assignation should be made by certain limits, so that it might be known where, and by what places, and how much, each man should be obliged to maintain.

"And that, when necessity should happen, by occasion whereof it might be requisite to withstand or resist the danger or violence of the sea, in repairing of the before specified banks, that the said twenty-four jurats should meet together and view the places of danger, and consider to whom the defence of the same should be assigned, and within what time to be repaired.

"And that the common bailiff of the said marsh should give notice to those unto whose defence the said places should be assigned, that they should defend and repair them within the time assigned by the said twenty-four jurats; and if they neglected so to do, that then the said common bailiff should, at his own charge, make good the said repairs by the oversight of the twenty-four jurats; and that afterwards the party so neglecting should be obliged to render to the said bailiff double the charge so laid out by him about those repairs, which double to be reserved for the benefit of the said banks and the repair of them; and that the party so neglecting should be distrained for the same, by his lands situate within the said marsh.

"Moreover, in case any parcel of land should be held in common by partners, so that a certain place could not be assigned to each partner for his own proportion, viz. a whole or a half perch, in respect of the small quantity of land; that then it should be ordained by the oaths of the twenty-four jurats, and viewed what proportion of the said land so held in common he might be able to defend; and, therefore, upon a certain portion so to be defended by the said partners in common, to be assigned to them. And if any of the said partners should neglect to defend his portion, after admonition given to them by the bailiff, the said portion of the party so neglecting to be assigned to the other partners, who ought to make the like defence; which partners to hold the portion of the party so neglecting in their hands, until he should pay his proportion of the costs laid out about the same defence, by the oversight of the twenty-four jurats; and also double towards the commodities of the said banks, and the repair of them as aforesaid.

"And that if all the partners should happen to be negligent in the premises, then that the common bailiff before mentioned should make good the whole defence, at his own proper costs, and afterwards distrain all those partners in double the charges so by him expended in the said defence, by view of the twenty-four jurats as aforesaid; saving to the chief lords in the said marsh the right which they have against their tenants touching this defence according to their feoffments.

"And that all lands in the said marsh be kept and maintained against the violence of the sea, and the floods of the fresh waters; with banks and sewers, by the oath and consideration of twenty-four jurats at the least, for their preservation, as anciently had been accustomed."

Such were the first laws formed for the guidance of the commissioners of sewers, and we learn that soon after their publication, Henry III. was informed that his haven at Rumenale or Romney was likely to be destroyed, unless the river of Newendene, whereupon the said haven was founded, was again turned into its original channel, from whence it had been diverted by the overflowings of the sea. Various obstructions in the old course of that river were removed, a new channel was opened, and a sluice built at the town of Apeltre, "to allow the salt water to enter into the said river, by the inundation of the sea from the parts of Winchelsea, and that it might join the fresh water of the river in its ancient course, and thus in its descent be made to scour out the haven." Another sluice was also made at Sneregate, and a third in the port itself, where the water passed off into the sea to prevent the tide from entering the river; the whole of these works were performed under Nicholas de Handloo and twenty-four jurats, named by the sheriff of the county of Kent.

Edward I., in the sixteenth year of his reign, finding that the sea banks and water-gangs on the coast needed reparation, issued a commission to John de Lovetot and Henry de Apuldrefeld, to inquire by whose default this damage had occurred, and, together with the bailiffs and others, to distrain upon all those whose negligence had been the cause.

These commissioners confirmed the ordinances of Henry de Bathe, and assigned the election of the king's bailiff to the lords of the marsh in future.

In the eighteenth year of the same reign, some controversies and differences again arising relative to those upon whom the expenses of repairing and maintaining the sea-walls should fall, another commission was appointed, in which were named John de Lovet, Robert de Septuaus, Thomas de Gudinton, and Henry de Appletrefeld.

Some few years afterwards, Henry de Appletrefeld and Bertram de Tancrey were desired to make a general survey of the whole coast of Kent, examine its banks and ditches, which by reason of the roughness of the sea were in many places broken, and after making their report, they extended the ordinances of Henry de Bathe by common assent to every hundred and township throughout Kent, as well as the coast bordering the Thames and other waters, wherever there were marsh lands subject to inundation.

The ordinances now so generally promulgated were, "That through all other maritime places in the said county liable to the danger of the sea, the river of Thames, or any other water, wherein the marsh law had not formerly been established and used, and that divers perils, through defect of banks and water-gangs, had there happened: lest therefore for the future the like or worse might accrue.

"That in every hundred and town, as well by the sea coast as bordering on the Thames and other waters, in which the marsh lands are subject to inundation, there be chosen and sworn twelve or six lawful men, according to the largeness of the hundreds or towns, and who have lands in danger of the sea, the Thames, and other waters; which men to be assigned keepers of the banks and water-gangs in the hundreds and towns aforesaid, who upon their oath shall keep safe the said banks and water-gangs; and when, and as often as need requireth, repair them, as also shall, in respect of the raging of the sea, raise the said banks higher by 4 feet at the least than formerly they were, and make them of thickness answerable to that height.

"For the reparation of which banks and water-gangs, when need shall so require, the charge to be raised in manner following, viz., that all and singular persons having lands liable to the danger, whether situate near or afar off, forasmuch as they have preservation by those banks and water-gangs, they shall contribute for the quantity of their lands and tenements, either by number of acres or carucates, according to the proportion of what they hold, so that no tenant of these lands or tenements, be he rich or poor, or of what order, state, dignity, or condition soever, either within liberties or without, any favour shall be showed in this matter.

"That in every place for the levying of the said costs and charges, and faithfully laying it out upon the said banks and water-gangs, two lawful persons out of the said sworn men be assigned, who, together with the bailiff of the liberties or lords of the fee, shall make distresses for the same.

"And when the before specified banks shall be, according to the ordinances of the jurat,

so repaired at the common charges, that there shall be assigned to every man his peculiar portion of the bank by certain places and bounds, to be sustained at his own proper cost, according to the quantity of his tenement, and number of acres subject to that danger, so that it may be known where, and by what places, and to what portion every man is so obliged to make defence. And if any shall be negligent in paying their portions of the said contributions at the day appointed by the jurats for that purpose, or in his portion for repair of the banks, that he be distrained by his goods and chattels wheresoever they should be found, within liberties or without, till he have contributed his share, and paid his charge of the said banks with double costs, which double to be reserved for the common benefit of the like repair in these parts.

"And that these distresses shall be made by the collectors of the said costs, together with the bailiffs of the liberties or lords of the fee, and being so made, to be kept for the space of three days at the most, if they upon whom they shall be made be stubborn or negligent for so long time, and then forthwith sold, in respect of the perilous rage of the sea imminent. And if as well the collectors as tenants shall be found negligent in performing the premises, that then every lord of the fee within the compass of the fee shall cause the said banks and water-gangs to be repaired at his own proper charge, and the costs that he shall be at therein, together with the double thereof, he shall cause to be levied upon the goods and chattels of those that are negligent for his own use.

"And that no shrieve of Kent for the time being, or his bailiff or officer, shall take any distress touching the banks and water-gangs in any marshes, nor thenceforth meddle at all neither with the distresses taken by the lords of the fee, bailiff of liberties, or collectors of the costs or contributions to the said banks and water-gangs, nor distrain them by writ of replevin, nor deliver them by surety or pledge any manner of way.

"And it was also ordained and concluded, that if the jurats so chosen for the custody of the banks and water-gangs, whether they shall be of the marsh of Rumenale, or of other maritime lands, do refuse to come at the summons of their bailiffs, for the necessary repair of the said banks and water-gangs, they shall, for that their negligence, be punished by their bailiffs, as in this marsh of Rumenale they had been heretofore accustomed.

"And that the collectors also of the costs bestowed in repair and support of the banks and water-gangs, after the said repairs are perfected, shall forthwith make their account before the jurats and bailiff of that county, as well within the marsh of Rumenale as without, of all monies assessed and levied for the before specified repairs; as also for the double, whensoever it may fortune to be levied; and if they shall not do so, then to be distrained by the bailiffs of the country or place, to make account thereupon, saving always to the chief lords of the fees their right which they have, and hitherto had wont to have, touching the defence of their lands according to their feoffments, and of levying the double according to ancient custom used, as it is contained in the ordinance of the said Henry de Bathe."

These ordinances were held in such high esteem, that they were constantly confirmed and issued by the crown wherever it was necessary: in the thirty-fifth year of Edward III., some further penal statutes were annexed, and in the sixth year of Henry VI. several commissioners of sewers were appointed and empowered in various parts of the kingdom, "to make and ordain necessary and convenable statutes and ordinances, for the salvation and conservation of the sea banks and marshes, and the parts adjoining, according to the laws and customs of Romney marsh."

In the succeeding reigns the same statutes were continued, with some minor alterations and additions, and no material change took place until that act was passed in the twenty-third year of Henry VIII., in which it is provided, "that commissioners of sewers shall be directed in all parts within this realm from time to time, where and when need shall require, to be formed of such substantial and indifferent persons as shall be named by the lord chancellor and the two chief-justices for the time being; any six commissioners, of whom three must be a quorum, may act as the king's justices, to survey the walls, ditches, banks, gutters, sewers, gates, calcies, bridges, streams, and other defences, lying within the limits assigned, and also all fishgarths, milldams, locks, ebbing wears, keeps, floodgates, and other like annoyances, and the same cause to be made, corrected, repaired, amended, put down, or reformed, as case shall require, after their wisdoms and discretions, as well according to the statutes and ordinances already made, as by the authority of the present ordinances, after ascertaining by a jury the persons equitably liable to the charge of such works, and the proportions in which they ought to be assessed."

The commissioners are empowered to appoint keepers, bailiffs, surveyors, collectors, expenditors, and other ministers and officers, who shall account to them, and also to impress workmen, take materials, waggons, carts, &c., to make statutes and ordinances for the safeguard, conservation, redress, correction and reformation of the premises, after the laws and customs of Romney Marsh in the county of Kent, or otherwise. This statute was made perpetual by the third and fourth of Edward VI., and is the existing statute of sewers.

Under these several acts the various breaches which took place from time to time in the Thames banks were repaired, but in spite of the several commissions, it appears from a representation made to parliament in the fifth year of Elizabeth, that upwards of 2000 acres of land had laid thirty years under water in the parishes of Erith, Lesnes, and Plumstead, which in former times were excellent pastures. It was also represented, "that one Jacobus Aconytus, an Italian, and servant to the queen, had undertaken at his own charges the recovery thereof, in consideration of a moiety of it for his charges; but that the lords and owners thereof were many, and had several kind of estates therein, whereby their assents and good assurances could not be procured. It was therefore enacted that the said Jacobus and his assigns, and their servants, factors, and labourers, &c., should at the cost and charges of the said Jacobus after the tenth day of March, in the year 1572, for the term of four years then next following, inn, fence, and win the said grounds or any parcel of them; and that having so won and fenced the same or any of them, that he the said Jacobus and his heirs, or such person or persons and their heirs as he or his executors should nominate, by their writing enrolled in one of the said queen's courts of record at Westminster, or by his the said Jacobus's last will and testament, in consideration of such recompense, should have and enjoy the one moiety thereof, to be severed from the residue, within two years next after the said winning thereof, by four or more discreet commissioners, to be nominated and appointed by the lord chancellor, and being so severed, lots to be cast for concluding of each portion to either parties.

After the two years had expired, "there were only 600 acres won and inned with walls, banks, &c., which afterwards, by the violence of the floods, were again overflowed and lost," and Jacobus Aconytus then deputed John Baptista Castilion, John Gresham, and others, to undertake the work, and after many years' fruitless attempts, it was enacted that William Burrell of Ratcliff, in the county of Middlesex, gentleman, should have power to enter upon the work, and to take reed and earth, in any part of the said drowned marsh, so as he the said William, nor any employed therein under him, should not dig within twenty rods of any wall already made within that marsh, and that immediately after his accomplishment of the same, he the said William, his heirs and assigns, to have the one-half of all the said grounds so to be inned, according to the purport and true meaning of the said recited indenture, the other moiety to belong to the owners of the said marsh grounds, according to the several proportion of their quantities which they had in those grounds, to be holden of Edmund Cooke, Esq., his heirs and assigns, as of his manor of Lesnes and Fants in free soccage by fealty, and one penny rent for every acre, and not in chief, nor by knight's service. And that in consideration of the great charge of this work, the said inned marshes to be discharged from all tithes and tenths whatsoever, for and during the term of seven years next after the inning, winning, and fencing the same."

We are not informed how long the work was in operation, but it was effectually accomplished, after considerable difficulty, early in the 17th century.

In the month of September, 1621, the whole of Dagenham Level, on the Essex side of the river Thames, was thrown under water by an extensive breach being made in the walls; this was speedily repaired by Cornelius Vermuden, of Saint Martin's Dyke, in the island of Tholen, near the mouth of the Scheldt, a gentleman expert in the art of banking and draining; and as many of the owners refused to pay their proportion of the expenses, a portion of the land reclaimed was assigned to Vermuden by the king's letters patent, which recited, "that where any person should be assessed by the commissioners of sewers to any lot, and refuse or neglect to pay the same, the land to be leased, or passed in fee simple, in recompense to the undertaker."

Drainage of the Fens in Lincolnshire, one of the most important, as well as one of the earliest works, in this branch of engineering, executed in England. These fens were entirely inundated by the sea, though there is strong evidence for believing that previous to their being covered with water, they formed a woody country, "oak trees being frequently found at a depth of 3 feet or more beneath the surface, lying near their roots, which still stand as they grew in the firm earth below the moor, and the bodies for the most part north-west from the roots, not cut down with axes, but burnt asunder somewhat near the ground. Some of these trees are 5 yards in circumference, and 16 in length, and many have acorns remaining near them. There are also fir trees which lie 1 foot or 18 inches deeper; many of them are more than 30 yards in length," and according to Dugdale, one was taken out in the year 1653, "36 yards long without the top, which was lying near the root, which stood likewise as it grew, having been burnt and not hewn down, which tree bore at the bottom 10 inches square, and at the top 8."

A ladder of fir was found in the moors at Thurne, with about forty staves, which were 33 inches asunder, and at Haxey Carr a hedge with stakes and binders. So many trees are found here, that the inhabitants have, on an average, taken up, says the same author, 2000 cart-loads in a year.

No memorial is left which can lead to a conjecture of when this vast inundation took place; but without doubt it was occasioned by the elevation of the beds of the several rivers

flowing through it, the chief of which are the Trent, the Ancholme, the Witham, the Welland, the Glen, and several tributary streams. In the reign of Henry II. the whole of this district was one vast lake, for we find an account of shipping traversing it in all directions. The great bay or estuary into which these different rivers are discharged is very shallow, and full of shifting sands and silt, and the rivers flowing through a soft soil bring down a great deal of mud, particularly in times of flood, which is met by the tide, also charged with silt, and prevented from being carried away; thus both are deposited at the mouth.

In wet seasons the rivers, from the greater quantity of water, run to seaward with increased velocity, and of consequence drive the silt further out; when this quantity is lessened, and the tides are stronger from the effects of the wind, the silt is driven less powerfully outwards, and settles near the mouths, which chokes them up, and prevents their free discharge from the fens. Such may be some of the causes for the inundations that have taken place. There is no doubt that much was effected by the Romans in this district to confine the course of the several rivers, and prevent their frequent overflow.

The marshes on the river Ancholme are mentioned in the sixteenth year of King Edward I., who directs his writ to the sheriff of the county of Lincolnshire, to inquire "whether it would be hurtful to him, or any other, if the course of that river, then obstructed from a place called Bishop's Brigge to the river Humber, were opened, so that the current of the same might be reduced into its due and ancient channel," and commissioners were afterwards appointed to cause the channel to be scoured and cleansed.

The Island of Ancholme, which contains some of the most fertile land in the county, was formerly nothing but fen, occasioned by the silt thrown up the Trent with the tides of the Humber. The obstructions which the Dun and Idle met with forced back their waters over the neighbouring lands, so that the centre of this district, which was somewhat more elevated, formed an island. One of the works performed here to prevent inundation in the reign of Henry V. was a strong sluice of wood, made upon the Trent at the head of a sewer, called the Mazedyke, which was of a sufficient height and breadth to keep out the tidal water, as well as to prevent the fresh water descending from the west part of the same sluice to the sewer into the Trent, and from thence into the Humber. This sluice was destroyed by some of the inhabitants of the lordship of Hatfield, and rebuilt by John de Shireburne with stone, sufficiently strong, as he thought, for defence against the sea-tides and fresh waters. The jurors, however, condemned it, being inadequate for its purpose, and both too high and broad; they also ordered in lieu of it, "that sluices of strong timber should be set up, which should consist of two flood-gates, each containing in itself 4 feet in breadth, and 6 feet in height; and also a bridge upon the said sluices, in length and breadth sufficient for carts and other carriages, which for the future might pass that way."

No great engineering works appear to have been undertaken to rescue this vast fen or lake, which extended over upwards of 60,000 acres, till the beginning of the reign of King Charles I. That monarch seems to have authorised the draining of all the surrounding marshes of the Isle of Ancholme, as well as those of Hatfield Chase and Dykesmarsh, which were overflowed by the Idel, Bickersdyke, Turne, Done, and Ayre rivers, in consequence of their being obstructed by silt, so that boats could navigate the country at all times.

Haxey Carr had boats laden with twenty quarters of corn usually passing over it from the river Idel to Trent. The king being the owner, not only of Hatfield Chase, Dykesmarsh, and other townships so inundated, contracted under the great seal with Cornelius Vermuden of the city of London, in the second year of his reign, "that the said Cornelius should at his own charge drain and lay the same dry, beginning the work within three months after the said king should have agreed with those persons that had interest of common therein, and finish it with all possible expedition.

"That the said Cornelius, in consideration thereof, should have to him and his heirs for ever one full third part of the said surrounded grounds, to hold of the said king, his heirs and successors, as of his manor of East Greenwich in free and common soccage.

"That he the said Cornelius should pay and satisfy to the owners of all lands lying within the same level, and so surrounded, such sums of money as the said lands should be thought worth by four commissioners, whereof two to be named by the Lord Treasurer of England for the time being, and the other two by him the said Cornelius.

"That the said work being finished, there should be, for the better preservation thereof, a corporation made to make acts and ordinances to that end, as occasion should require, consisting of such persons as he the said Cornelius and his heirs did nominate.

"That within three years after they should be finished, six commissioners to be appointed, viz. three by the Lord Treasurer of England, three by the said Cornelius, his heirs, &c., to view them, and to estimate what the future yearly charge might amount unto for the perpetual maintaining of them: whereupon the said Cornelius to convey and assure the inheritance of lands to such a value as might be thought sufficient to support that charge;

and that whereas divers did claim common of pasture in sundry of the said grounds, it was agreed that the king should issue out his commission under the great seal of England to certain persons to treat and conclude with those commoners, by way of compensation in land or money concerning the same. Commissions were accordingly directed to several gentlemen of those counties to treat with the several parties who had right of common; and the whole being submitted to Sir John Bankes, the Attorney-General, he made an award, viz.: that of 13,400 acres belonging to that manor, which was then to be drained with the rest of the level, 6000 should be allotted to the commoners as their part or portion, lying next to the towns, and so preserved for ever at the charge of the said Cornelius Vermuyden, and the remaining 7400 acres to be set out in the remotest parts of those wastes to Sir C. Vermuyden and his participants for their third part, and for the said king's part in right of his interest as lord of the soil, which by consent was decreed in the Exchequer Chamber, and possession thereupon established with the said Cornelius Vermuyden and his participants, and to their assigns."

When this agreement was made the work was commenced, and in five years, after an expenditure of 55,825*l.*, it was completed; the water which had overflowed the entire level being conveyed into the Trent through Snow sewer and Althorpe river, by a sluice, which allowed the issue of the drained water at every ebb, and kept back the tide at the flow. These fen lands are rendered more difficult to drain in consequence of there being no calcareous strata separating the Kimmeridge and Oxford clays, as is usually the case, but which are here found in contact, and extend to a very considerable depth. These strata, not allowing the water to percolate, can only be drained by conducting it away on the surface, a great obstruction to which, is the low level of the entire district, which has little fall towards the ocean, indeed in many parts is absolutely below it.

Soon after the drainage of this district, the town of Sandtoft was built and inhabited by 200 French families, or Walloon protestants, who had fled from their native country to enjoy the free exercise of their religion, in the year 1642, and the inhabitants who had been deprived of their rights of common broke down the fences and inclosures of 4000 acres, destroyed all the corn growing, and demolished the houses; they pulled up the flood-gates of Snow river, let in the tides from the Trent, and again laid the greater part of Hatfield Chase under water.

The inhabitants of the island of Ancholme three years afterwards threw down many of the banks that had been constructed to keep the rivers in their course, filled up many of the drains, and altogether laid waste 74,000 acres; and it was not till the year 1656 these injuries were redressed.

The marshes which lie on the north-west of Lincolnshire, upon the borders of the river Ancholme, were drained in the year 1639, at the expense of Sir John Munson, "a person," says Dugdale, "eminently qualified with learning, and sundry ample endowments, who, out of a noble desire to serve his country, undertook the work and accomplished it."

The low lands on the south side of the Humber, and on the sea-coast in the province of Lindsey, were very ineffectually drained in the time of Henry III., although we find that a sewer was opened for the purpose betwixt the towns of Brunthorpe and Orreby, which was regularly scoured, cleansed, and repaired, by casting out the earth on each side, and that various bridges were built over it for the convenience of the adjoining landowners.

In the reign of Edward I. a writ was issued to John Beeke and the sheriff of the county, to inquire if the river Friskney could be diverted and brought to the town of Grimesby, for the better opening of that port, which was then silted up; and in the succeeding reigns many new sewers were cut, and more effectual drainage obtained; flood-gates were made at the various dams to keep out the sea; these were in pairs, generally from 12 to 20 feet in width, and made of timber.

The manner in which the earth walls were set out in the time of Elizabeth in this district seems to have been by falls, for one then newly made at Skegnes by order of the commissioners that sat at Partenay, and which was commenced at a place called Ransom Hyrne, is described as having forty falls in length, from the north end of the said Ransom Hyrne towards the south, and joining on, and closed to the old bank; this sea-bank measured 50 feet in the skirt, 14 feet broad at the top, and was 12 feet in height.

The Marshes of Witham lie on the borders of the river of that name, which extends from Lincoln to Boston; but its fall is so small, and the current so slow, that it could not be kept open either for the purposes of navigation or drainage, without constant cleansing from both mud and weeds. The navigation to Lincoln, which is now only sufficient for the passage of small craft, was attempted to be improved in the reign of Henry VII. by Mayhave Hake of Graveling, who brought with him from Flanders fourteen masons and labourers, to make a proper sluice and dam near the town of Boston. Mayhave Hake received four shillings a day, the masons and stone hewers five shillings per week, and the labourers four. The iron work required was made at Calais: among the items mentioned for making this sluice were, small cramps and large, chains, hookes, bolts, scherys, maunds, pannes, troughs, water scoops; and the price of the iron seems to have been two pence per

pound. After the work was completed, the engineer received in addition to his pay the reward of fifty pounds.

To the north, and north-east of the Wetham, lie other large fenny districts, called Wildmore Fen, West and East Fens; these are drained by an outfall, at Wainfleet Haven.

No general survey having been made during the middle ages, or any of the levels properly taken, the country comprised within this great fenny district was but very imperfectly drained. All the sluices were much too small, and the water courses so confined that they could not carry away the superabundant waters to the sea. The commissioners appear generally to have been guided by the wishes of the inhabitants of the particular district where any inquiry was instituted, and they were often misled by either the prejudice or ignorance of the engineers consulted.

In the summer time there is so much deposit at the mouths of the several rivers or washes, that the floods of winter cannot scour it away, though these often pour down in such abundance that they over-ride the gates, and flow over the fens.

At the latter end of the last century considerable attention was paid to this district, and vast sums of money expended for its improvement. Deeping Fen, which was drained by three wind engines above Spalding, where the waters were lifted into the river Welland, has now a deep canal cut, which conveys them into the Witham, below Boston.

The fen which extends from Tattershall to Lincoln has been greatly improved by embanking and draining, under an act passed in the year 1787, and a new cut has been made from Bishop Bridge to the Humber, for the drainage of the Ancholme district. The Wildmore, East, and West Fens have outlets at Anton's Gowt, and Maudfoster; one 2⅛ miles above Boston, the other a little below it; these are consequently more effectually drained; besides which, there is a cut from Midlam Drain at Swinecoat's inclosure, which continues for 11½ miles, with a fall of from 3 to 4 inches per mile, and for 13 miles with little more than 2 inches per mile during neap tides.

Catch-water drains have been made, which skirt the high lands near the Witham, in Coningsby, and receive all the waters that can be collected; the locks are so constructed that the navigation is not impeded.

The Bedford Level. — Mr. Samuel Wells published in 1830, in two octavo volumes, a complete history, accompanied by a map, of this singularly interesting district.

The great fen comprehends the low lands on each side of the bay called the Wash, and is about 60 miles in length, and from 20 to 30 in breadth.

The area of the Bedford Level contains about 530 square miles, or 340,000 English acres, and on the east are the high lands of Norfolk, Suffolk and the wolds of Lincoln, which consist of chalk: westward the high grounds are composed of sandstone and oolite, and the substratum of the level is alluvial marle or sand, formed by deposition of the upland waters, wherever met by the tide. This deposit, when its accumulation is above the level of neap tides, forms a salt marsh, only overflowed by spring tides: when the surface is elevated, by vegetation partially intercepting the sediment of the upland streams, it then becomes fen, through which the rivers are constantly forming new channels.

Eleven rivers bring off the waters from the high lands, and form the natural drainage; these are the Witham, the Glen, the Welland, the Nene, the Cam, the Great Ouse, the Lark, the Brandon or Little Ouse, the Stoke, and the Wessey. All these are collected into four outfalls,-viz. the Witham, the Welland, the Nene, and the Ouse. History tells us that the Romans commenced the drainage of this highly productive soil, and formed embankments still visible at Wisbeach and Lynn, and in the Carr dyke, which extends from Peterborough to Lincoln. Around Horsey, near Stand Ground, Erith, Bodsey, and Worlich, numerous lines of forts or stations may be still traced.

In the reign of Henry VIII. an act was passed for regulating the commissioners of sewers, but it specifies no powers for making new drains; other acts were passed in the reign of Elizabeth, in 1572, and five years later; but in the forty-third of Elizabeth, 1600, a general drainage act was passed which extended over all the marshes and drowned lands of England.

During the reign of James I. the crown lands were taxed for the purpose of drainage, and two commissioners were appointed to treat with the parties interested: Richard Atkins was employed to bore the fens 11 feet deep; and a plan of drainage was laid down, by forming a new channel for the Nene, from the town of March to Salter's Lode. Also to cut straight the channel from Ouse to Erith, where the Ouse at low water was 10 feet below the soil of the fens. The first of these is now called Popham's Eau, and the latter the Bedford River. Land drained under Hayward's survey, made at that time, amounted to 307,242 acres.

Sir John Popham, the Lord Chief Justice, and others, undertook, in 1605, to drain all the fens between the Ouse and the Deeping, and were to retain for their trouble and outlay 130,000 acres. Popham's Eau, which was executed under Atkins's direction upon on enlarged scale, was opened in 1606: seven years afterwards the banks yielded to a very high tide, and considerable damage was done to them, to repair which cost 40,000*l.*

In the year 1631, Sir Nicholas Vermuyden was consulted upon the subject, and his first work in England was to complete the embankment of the Dagenham marshes; after which he drained Hatfield Chase.

Ninety-five thousand acres were to be given as a reward for draining the great level, which was undertaken by a company of adventurers, with the Earl of Bedford at their head, he at that time possessing 20,000 acres in Thorney and Wittlesey.

The works were entrusted to Vermuyden, and carried into effect in the following order:— The old Bedford river, 21 miles in length, and 70 feet in width, was improved from Erith to Salter's Lode; same cut from Feltwell in Norfolk to the river Ouse; Sandy's Cut, near Ely, 2 miles in length, and 40 feet in width; Bevill's Leam, 10 miles long, and 40 feet in width, from Wittlesey Mere to Guyhorn; Morton's Leam; Peakirk Drain, 10 miles long and 17 feet wide; New South Eau, from Crowland to Clowes' Crop; Hell's Cut, near Peterborough, 2 miles long and 50 feet wide; Shire Drain, from Clowes' Crop to Tyd and the sea; two sluices on the Shire drain; a clow or clough at Clowes' Cross, a kind of sluice, in which the aperture is closed by a sliding board in the manner of a *porte coulise*; a great sasse, or navigable sluice, through which any thing could pass at pleasure, at the end of the well creek at Salter's Lode; another stone sluice at the mouth of the Bedford river; a sluice at Erith; a larger one at the Horse Shoe, below Wisbeach, to keep the tide out of Morton's Leam.

In the year 1635 a charter of corporation was granted to the Earl of Bedford and others, and the work having been declared complete, the 95,000 acres were set out by his Majesty's surveyor, which were, however, only summer lands.

The law by which this allotment was made was reversed, and the Earl of Bedford died in 1641, the victim of disappointment.

Vermuyden divided the fens into the North, Middle, and South Levels; the space between the Welland and Nene was called the North Level; and the first of these rivers was protected by a bank 70 feet wide at the base, and 80 feet high. The Middle Level eastward of the Nene, was protected by Stand Ground Sluice; and the waters of the Ouse were confined for some distance by a bank 60 feet wide at the base, 10 feet at the top, and 8 feet in height. In the South Level a new river channel was made, 120 feet in width, and 10 feet in depth, with sluices at each end.

Vermuyden, who had studied in Holland, seems entirely to have mistaken the nature of the English fen district, his whole scheme being directed to keep out the sea, sluices being placed at the ends of all his canals, as well as those of the natural rivers, for this purpose. His object should have been, by raising the embankments of the great drains, to allow the tidal waters to flow freely up them, and thereby prevent the mouths of natural and artificial outlets from being choked up.

The sea never rises above a certain known level, and banks may be always formed to keep it out; in these districts there is more to be dreaded from the freshes after heavy rains, and to collect and allow them a free passage into the ocean is the most important consideration. The passages or drains should be cut as straight as possible, the current being regulated by the declivity of the bed, and this will be greater as the line is shorter: 3 or 4 inches per mile constitutes a moderate current; consequently if the distance is doubled with the same fall, scarcely any current is obtained. All obstacles, as sluices, which prevent the tide entering or the drainage water from freely passing off, should be avoided. Three inches fall per mile makes a slow movement, 4 inches a moderate velocity, and sufficient for all draining operations, so that any sill laid down at the mouth of a river, 3 feet above the proper level, will have the effect, where the fall is 3 inches to a mile, of obstructing the natural drainage for 12 miles above it. A drainage outlet obstructed by sand banks has the same effect, the fall being lessened in consequence of the deposit at the mouth. Free ingress should always be given to tidal water, and the banks of the river raised sufficiently high to obtain a good and perfect fall, and the course should be as straight as circumstances will allow, that none of the advantages be lost. An increased downfall, as well as tidal water, may be also rendered efficacious in removing old sand banks, and is the best method of scouring a harbour.

The Eau Branch cut, opened in 1821, and excavated under the direction of Mr. Rennie, was one of the greatest improvements effected in this district: its cost was 33,000 pounds; and the first winter it was opened the river channel from Denver Sluice to Lynn was scoured 5 feet, since which time it has gradually deepened itself nearly 15 feet on an average: all the outfall sluices on each side of the river, and the beds of the drains have been lowered, and the windmills used are no longer required.

This was originally projected by Nathaniel Kinderley, about 1720, and was intended to conduct the Ouse by a direct cut from Eau Bank to Lynn, a distance of only 2½ miles, instead of allowing it to flow 5 miles. The tide in Eau Bank flows three hours, and rises in that time 15 feet; thus leaving nine hours' ebb.

The Nene Outfall is a new tidal channel, carried through the light sands which border the Lincolnshire coast; that portion which is artificially formed commences about 6 miles

from Wisbeach, near Buckworth sluice, and extends a distance of 6½ miles to Crabhole, from which place a natural channel 1½ mile in length opens into the German Ocean at Wisbeck Eye.

The excavation was commenced under Mr. Rennie's direction in August, 1827, when the old channel was closed up, and the course of the new river became deepened 12 feet and upwards by the scour of the tidal current, the sides being secured by a thick coating of stones.

The breadth of the bottom of the river is 200 feet at the lower end, and 140 feet at the upper, near Kinderley Cut; the depth from the surface of the ground adjacent to the bed of the river is 24 feet throughout, and the width at the top varies from 200 to 300 feet. An ordinary spring tide rises 22 feet at the lower extremity, and 18 feet at Kenderley Cut junction.

Over the channel at Suttonwash a bridge has been constructed, and an embankment carried across the estuary to Cross Keys in Norfolk. 1500 acres of land embanked from the sea are under cultivation, and 6000 more are rapidly becoming fit for the same purpose.

The water in the new channel ebbs out every day 10 feet lower than formerly, opposite the South Holland and North Level sluices, which are outlets for 100,000 acres of land, lying between the Nene and Welland, now efficiently drained without the aid of windmills or steam engines.

The North Level, containing 48,000 acres, benefitted materially from this work; a new sluice was built for the discharge of the waters into the Nene Outfall, at a level 8 feet below that which conveyed them into the old channel of the river. The width of the waterway of the old sluice was only 17 feet; the new one was increased to 36 feet.

A new main drain 8¼ miles in length was made from the last mentioned sluice to Clowes' Cross, 8 feet deeper, and of a capacity six times greater than the old one; the declivity of the bed is throughout 4 inches per mile.

From Clowes' Cross the new drainage is turned into the two channels called New South Ean, and the New Wryde, which now receive the waters from the whole of the North Level.

The Wisbeck district contains 15000 acres, and benefits materially from the Nene Outfall: all the drains are navigable, which was not the case with with the old ones. The total expense of the Nene Outfall was 200,000*l.*, and that of the North Level drains about 150,000*l.*

The Nene Outfall, projected by Mr. Rennie, was completed by Mr. Telford and Sir John Rennie; and the scheme of the North Level drainage was entirely the work of Mr. Telford, who first made use of the natural outfall, to which no previous attention had been paid, and removed all the drains and sluices which acted as obstructions; he also returned to the better principle of admitting the influx and reflux of the tide; thus maintaining the channel clear by the constant scouring. The fall given in some instances is 4 inches, and in others 9 inches per mile, and the banks or side slopes have a fall of 2 to 1.

A catch-water drain was executed by Mr. Rennie, for the purpose of draining the Wildmore Fen, which had no outlet, and comprised upwards of 75,000 acres. The lower part of this fen was a watery waste, containing 15,000 acres; it is now inhabited, and its land highly productive. The whole cost of this work was 650,000*l.* The windmills and their machinery erected by the Dutch engineer to lift the water from the lower ditches into the upper, that it might pass off to the sea, are no longer necessary, and the annual expense of maintaining them is consequently saved.

All the outfalls of the rivers of this district were affected by the tides, and particularly by those which flowed up the Ouse: at Lynn, where the water was always thick and muddy, a large proportion of silt was left behind. In deepening the Wisbeach river at the beginning of the seventeenth century, beds of stones 8 or 10 feet below the then bottom was arrived at by the workmen in sinking for a sluice, and in it were the remains of several boats.

These stoppages must, at a very early period, have produced a most unhealthy stagnation of waters, and a vast deposit. On sinking the foundation of Skyrbeck Sluice, near Boston, at a depth of 16 feet, a smith's forge was discovered, with all the tools, horse-shoes, and various other things. The country about the monastery of Croyland is described before any material change was made by draining, in the history of the religious hermit who first resided there; the writer of the life of S. Guthlake has beautifully personified all the demons which haunt a morass; and this of Croyland must have been most abundant in whatever could render it wretched. When the saint awoke in the dead of the night, he discovered his wooden cell full of black troops of unclean spirits, which crept in under the door, and at chinks and holes, and coming in, both out of the sky, and from the earth, filled the air as it were with dark clouds. In their looks they were cruel, and of form terrible, having great heads, long necks, lean faces, pale countenances, ill-favoured beards, rough ears, wrinkled foreheads, fierce eyes, stinking mouths, teeth like horses, spitting fire out of their throats, crooked jaws, broad lips, loud voices, burnt hair, great cheeks, high

breasts, rugged thighs, bunched knees, bended legs, swollen ankles, preposterous feet, open mouths, and hoarse cries. A vivid and too correct a description of a population, born and dwelling in such a pestilential marsh, and one which should animate not only a government, but every individual of the community to lend his aid in reversing: it ought to be felt as a stain upon the national philanthropy that many portions of the saint's dream are still realities.

In the time of Edward the Confessor, a firm causeway was made of wood and gravel across Deeping Fen, which reached from the town of that name to Spalding, for the use of passengers, and is described by Ingulphus as most sumptuous and valuable; various earth-banks were also thrown up by the Saxons to protect their habitations from inundation; but nothing appears to have been done by that people upon an extensive scale in the way of draining. The Romans are supposed to have constructed the Carr or Caer dyke, which acts as a vast catch-water drain to the whole North Level, and which would, if in a good condition, drain upwards of 12,000 acres. This great work extended originally from the river Nene, below Peterborough, to the city of Lincoln, and also to the Trent at Torksey. The fens adjoining the Wash are said now to contain 217 square miles, between the hills on the south and south-east, and the rivers Ouse and Cam; 394 square miles between these rivers and the Nene; 389 square miles between the Nene and Glen rivers, 414 square miles between the Glen and Old Witham; and 201 square miles between the Old Witham and Tetney drain; making a total of 1615 square miles, or 1,033,360 acres.

The fens are generally lower the more distant they are from the sea: the difficulty of drawing off the water is therefore considerably increased: but this has been most admirably effected, by paying due attention to the outfall, by preventing the upland waters from running or spreading over them, collecting it in catch-water drains, discharging it in the best manner, and always taking for a cut the shortest possible course towards the sea.

Much has been done to effect the drawing off the waters by improving the outfalls; but to get rid of it entirely, mechanical means are requisite. The Dutch mills pumped up considerable quantities; but not being regular in their movements, the steam engine has been generally adopted; at Deeping Fen, near Spalding, one supplies the place of forty-four windmills.

It is generally found necessary to raise the water from 3 to 4 feet; and for this purpose scooped wheels are made use of, the float-boards of which dip 5 feet below the water's surface, or 6 feet 6 inches below the land. The main drains are twelve inches deeper than the wheel track, and the scoop-wheels are made of cast iron, with wooden float-boards, like the undershot wheel of a water-mill; but with this difference, that they are moved by steam power, and lift the water. The float-boards move on a trough of masonry, into which they fit exactly, the lower end being open to the main drain, and the upper communicating with the river, which is kept out when the wheel is not at work by lock gates. The float-boards do not radiate from the centre of the wheel, but form an angle of 45 degrees with the horizon, at the point where they deliver the water. The diameter of the wheels is so contrived, that the surface of the water in the outfall river is never more in height than 4 or 5 feet above its axis, which prevents the water passing over the float-boards, and finding its way back again. The speed given to the circumference of these wheels is about 6 feet per second.

At Pode Hole, in Deeping Fen, a steam-engine of eighty horse power, and a water wheel of 28 feet diameter, with the float-boards of 5 feet 6 inches in depth, and 5 feet wide, moving at the rate of 6 feet per second, discharged 165 cubic feet of water per second; the float-boards dipping 3 feet 4 inches, and the average consumption of coal being 10½ pounds per horse power per hour. The expense annually in this district does not exceed 2*s.* 6*d.* per acre, independent of the first cost of the engine and machinery attached, which may be calculated at 20*s.* per acre.

Deeping Fen, consisting of 25,000 acres, has two steam engines of about 140 horse power.

Marchwest Fen, containing about 3600 acres, has a 40 horse engine: the same power is applied to Misterton Sas.

Littleport Fen, near Ely, has two steam engines of 110 horse power, to drain 28,000 acres: there were formerly seventy-five windmills. The scoop-wheel is 35 feet in diameter, and weighs 54 tons; the pinion is 4 feet in diameter, weighs 33 cwt., and makes thirteen revolutions in a minute: when the tide is high, this pinion works into a wheel 24 feet in diameter, having internal teeth; the float-boards on the scoop-wheel then move with a velocity of 212 feet per minute, and discharge in that time 3519 cubic feet of water. When the tide is low, the pinion is made to work in another wheel 16 feet in diameter, which has external teeth; the float-boards then move at the rate of 318 feet per minute, and deliver 5278 cubic feet of water in that time.

Middle Fen, near Soham, has 7000 acres drained by an engine of 60 horse power, and Waterbeach Level has a similar engine to drain 5600 acres. Other engines are employed in various districts; and it is surprising that so small a quantity of mechanical power is found adequate to drain such an extent of marshy land so effectually. It has been estimated

that on an average upon every 1000 acres, 7,260,000 cubic feet of water are annually raised and carried off; and a ten-horse steam engine performs this work in less than 232 hours.

The quantity of rain is computed at 26 inches; and if 3 inches fall in a month, allowing 1 inch or $\frac{1}{3}$ to be evaporated or absorbed, we shall have 7260 cube feet of water to the acre to be carried away by means of machinery, before the land can be rendered fertile.

The high lands which pour their waters over these fens comprise not less than 12,000 acres, and during a rainy season, as much as 40,000 cubic feet of water is sent down from them per minute, which is considerably augmented by that from the fens. This vast quantity was impeded in its passage to the sea by the narrowness of the three sluices through which it had to pass, viz. the Austins, which had an opening of 14 feet, Maudfoster, 13 feet, and Tichtoft, 4 feet. When the late Mr. Rennie was called in to survey and improve this extensive district, he commenced his operations upon a bold and noble scale: he shortened the course of all the rivers, made new cuts and drains in various directions, gave their beds an inclination of from 3 to 5 inches in a mile, formed a catch-water drain at the skirt of all the high grounds around the fens, and conducted the upland waters by an inclined bed of 6 inches to a mile, through a separate outlet into the head of the Eau Bank cut, into which all the drainage waters were conducted.

Thus the Great Level, as it is commonly called, is now more effectually drained, and once more redeemed from the state into which it had fallen after the dissolution of the religious houses in the time of Henry VIII., whose fraternities had paid great attention to keeping open the passages for the water, and the repair of the several banks, although not sufficiently aware of the advantages arising from opening and cleansing the natural outfalls of the drains, which the daily flowing of the tides choked up. It would be exceedingly advantageous if such a level could be placed under one direction, and not governed by persons interested in one district alone, and that, perhaps, the most remote from the point at which the waters are discharged into the ocean: no management could be effectual or beneficial to the whole body of proprietors, but one which should be established upon a system embracing the entire district to be drained.

Accurate maps and levels, meteorological observations, and the geological structure of the different portions of the district, together with a knowledge of the machinery in use for every kind of hydraulic work, should be acquired by the board, or the individual charged with so important and often costly work.

In the middle ages, before science was called in to assist at these operations, the rural engineer was content to confine the rivers with embankments of earth, raised 5 feet above the level of the land adjoining: these had sometimes a base of 18 feet, and a surface at top the same as the height: others with the same base and 6 feet high, had a width of 12 feet at the top, and these were calculated to keep out water in almost any situation: towards the water they were usually clayed to $1\frac{1}{2}$ feet in thickness, not only up the side, but over the entire top.

Sea banks were made 12 feet in breadth at top, and carried up 2 feet in height above the highest tides: these were sloped and turfed, and strengthened in various places with stakes, piles, and timber: sometimes rows of piles were driven parallel to the river at distances of 2 and 3 feet apart; and after uniting their heads by a plank, or weaving rods around them, the parallel spaces between were filled up with chalk or some other hard substance: thus the side of a wall towards a tidal river represented so many steps of piling and chalk, which frequently became more tightly bound together by the sea-weed. At times this method of defending the shore would be swept away altogether by the force of the tides when acted on by the winds, and a frightful breach would be the result, inundating extensive districts, and destroying property to a great amount.

Banks were sometimes made of sand, with twigs of the broom placed in horizontal layers, which, when properly clayed on the surface, and turfed, were found to stand in many situations remarkably well.

Loughs Swilly and Foyle, in Ireland. The first of these lakes has a communication with the Irish Channel by a narrow course, above which it spreads over a considerable tract of land, and afterwards narrowing again its breadth, joins the river Foyle about $4\frac{1}{2}$ miles above the town of Londonderry, where the channel is deep enough to allow the navigation of vessels of 600 tons burthen.

Lands of 25,000 acres, overspread by the tide, all alluvial, and gradually deposited, were undertaken to be reclaimed under the direction of Mr. Macneil, by the construction of a sea wall 14 miles in length.

Lough Swilly, from its width at the mouth, is more subject to be acted upon by the winds than Lough Foyle, and the highest tides rise 18 feet: here the first embankments were made, which reclaimed about 2000 acres. They were commenced as follows:—the soundings being accurately taken, the wall was set out in the most favourable position; a tide gauge was established, on which was permanently marked the height of high and low water. The slopes given to the embankment varied on the side towards the sea from 3 and 4 to 1, and

on the land side from 2 to 1. Culverts, 4 feet in diameter, founded on piles and cross timbers, with sluices and flood-gates on each side the wall, served to let out the water when the wall was completed, the gates being put at the lowest level of spring tides. The wing walls of these culverts, built of rubble masonry, were founded on a bed of concrete; these flood gates can be used either to admit the tidal waters for the purposes of irrigation, or for the passage of the land water; to carry away the silt that may accumulate in the channel catchwater drains are puddled, which collect the land waters on all sides, and convey them to the sluices with a proper fall.

The embankment contains within it a bed of puddle, 4 feet 6 inches in width at bottom, and 3 feet at top, and on the water side is placed a strong facing of fascines 6 feet thick at bottom, and 4 feet at top, embedded in the soil, and laid in an oblique direction, with a dip towards the land side; they are all held down by irons, which pass at right angles through their entire height. On the land side they are covered with sods of turf; the cost of this kind of embankment, including the sluices and puddle in the centre, is about 12 pounds per yard run.

Drainage of Towns.—Much has lately been written on the value of manures, and attention has been directed to the great waste which is permitted, by the sewers of the metropolis discharging their contents into the Thames, to be carried away by the current and the tide, injuring the quality of the water, and rendering the district through which it passes unhealthy; numerous plans have been suggested, by which much that is valuable to the agriculturist could be saved and made serviceable to the growth and improvement of vegetation. In Paris, where there are no sewers, every means is taken to prevent waste of that which is important to the wine-grower, and a considerable trade is carried on in the capital by collecting all that will serve for manure, and arrangements made to convey it to the most southern provinces. A vast portion of London might have its sewage directed into large reservoirs in the marshes, at a distance on each side of the Thames, where the contents might be separated and dispersed throughout the neighbouring district, or be conveyed by water to any part of the empire in need of it. The expense of such a scheme would be so small, compared with the immense advantages, that it is surprising public attention has not been directed to it; it has been computed that 1,000,000 tons of manure might easily be obtained annually, the value of which would be very considerable.

To carry out such a system, the property of individuals would perhaps be interfered with, and objections would be made to changing the character of the sewers; the most economical method is that of having movable casks placed in the vaults under the pavement, into which all the pipes of the dwelling might drain; and if these casks were arranged so that one was devoted to retain the solid matters and the other the liquid, or pipes laid to carry off the latter into the sewer, the valuable portions useful for manure could be easily carted away as often as it was found convenient. Such is the method practised by the company in Paris, and no inconvenience or annoyance is found to arise from it; the casks are the property of the company, who keep them in an excellent state of repair.

Before the fire of London, little or no attention was paid to carrying off the surplus waters from the city; it was suffered either to run upon the surface, or through the channels which the small streams had formed. After that calamity, it was enacted "that the number and places for all common sewers, drains, and vaults, should be directed by some one or more appointed under the common seal," and from this period we may date the authority of the commissioners of sewers in the metropolis; for some of the larger towns in the kingdom, similar enactments were obtained soon after.

Although the sewers in the city exceed in length 15 miles, it is still not thoroughly drained; one of the best constructed is that which carries off the waters from Moorfields, which is 7 feet in width, and 8 feet 6 inches in height. The other sewers vary in their dimensions; some are 4 feet 3 inches high, and 2 feet 3 inches in width, and others 5 feet by 3 feet, but none are made less than will enable men to enter and thoroughly cleanse them. The whole drainage of the city is into the Thames.

Westminster and a portion of Middlesex is under another commission, who have the control over 134 miles of arched or covered sewers, of which 93 are constructed with curved, the rest with flat bottoms.

Holborn and Finsbury districts comprise the northern parts of the metropolis.

The Tower Hamlets commission extends over 45 miles of sewer, and since the year 1830, upwards of 11 miles of new sewers have been built under its direction.

Surrey and Kent commission takes in the southern side of the metropolis; since the year 1820, nearly 21 miles of sewer have been constructed; previously the greater portion was only a surface drainage.

The Regent Street has a commission which manages its drainage, and there is so general a desire throughout the metropolis to have all the sewers covered or inclosed, that the open ones are fast disappearing, although the commissioners have no power whatever to make new covered sewers, by which the effluvia arising from them, so prejudicial to health, shall be confined.

There is also a great want of uniformity in the practice of the several commissions and their officers, which requires immediate improvement; among other points none is more important than the form given to the sewer, which differs in all the various districts. That used in Westminster has a curved bottom, perpendicular sides, and a semicircular top; that in Finsbury is the section of an egg, with the small end downwards. For every foot of the Westminster of the first class, 261 bricks would be required, and for the egg-shaped only 175, besides which for the latter there would be less digging. Others are built nearly cylindrical.

Recently, however, the egg-shaped sewer has been introduced by the commissioners for Westminster, with the large end downwards, which is certainly not the right position either for strength or utility; with the small end downwards, and carefully constructed, there would be less chance of compression or of the sides becoming foul.

Cast-iron inverts, bedded in lengths, are often used where the foundations are sandy or of a loose nature; they contain 8 or 9 feet superficial, are well adapted to take an extended bearing, and sustain the brickwork put upon them.

The outlets of many of the sewers which discharge into the Thames are protected by self-acting valves, which exclude the tidal water, and, in some instances, pen-stocks, under the direction and management of a resident attendant, are added, for still greater security.

Supply of towns with water.—The historian Stow most justly considered that, after the requisite arrangements for the defence of a city, the next subject requiring attention was a plentiful supply of good and wholesome water; and it appears that London, at the time of the Conquest, and for 200 years afterwards, received its water from the Thames, from the river of the Wells on the west, the stream which ran through Walbrook, and another through the ward of Langbourn, on the east. The suburbs were supplied by the Oldbourne, which fell into a stream called Wells, and numerous common wells, as the Holy, Clements, Clarks, Skinners, Fags, Tode, Loder, and Rads, well. In West Smithfield was a sheet of water called Horse Pool, and numerous wells were scattered over other districts.

These various streams and wells were constantly cleansed by the authorities of the city of London, but not being sufficient for the uses of the inhabitants, Henry III. granted to the citizens and their successors the liberty to convey water from the town of Tyburn to the city by pipes made of lead; and the first leaden cistern, built round with stone, called the Great Conduit in Westcheap, was erected in the year 1285; the whole length of leaden pipe then laid down from Paddington to the cross in Cheap was 1096 rods.

In the year 1401 a cistern was formed at Cornhill, and 22 years after bosses of water were made at Billingsgate, near Paul's Wharf; about 10 years after, Newgate and Ludgate gaols were supplied. Other conduits were afterwards established, at the expense of the city, and numerous leaden pipes laid down. These were annually visited by the Lord Mayor and wardens of the twelve companies; "they hunted the hare and dined at the head of the Conduit, and after dinner they hunted the fox, finishing the day with blowing of horns and merry-making."

A great portion of the citizens had, however, no other means of procuring this important article of domestic comfort than by fetching it from the Thames by the lanes that led down to the water-side. These lanes, in the course of time, were walled up at the end by those who occupied dwellings near, which became so great a grievance that an inquisition was established; several presentments were made by persons appointed out of the wards to inquire into the matter, and the evil complained of was considerably abated.

In the year 1582, Peter Morice, a Dutchman, showed the citizens that he could, "with pipes of lead and a most artificial forcier, standing near London Bridge, convey water into men's houses." This "forcier" is described by Stow as the first mill made to supply the city with Thames water, and he adds that it remained a long time the property of a Mr. Morice." The houses in and about Gracechurch Street were the first benefited by this "new device," and the water was remarkable for its clearness. Six years afterwards, Bevis Bulman set up another forcier near Broken Wharf, and conveyed the water to the neighbouring houses. In the year 1610, pipes of wood and stone were laid down by Thomas Hayes, to supply Thames water to the conduit at Aldersgate.

Such were the only means adopted for the supplying water to the metropolis until the year 1608, when Mr. Middleton commenced his important work of bringing the New River from Chadwell and Amwell to Islington. Stow tells us that whilst the work was in progress, he frequently, by favour of the owner, did divers times ride and see it, and diligently observed that admirable art, pains, and industry were bestowed for the passage of it, by reason that all the grounds were not of a like nature, some being oozy and very muddy, others again as stiff, craggy, and stony. The depth of the trench in some places descended full 30 feet, if not more, whereas in other places it required a sprightful art again to mount it over the valley, in a trough between a couple of hills, and the trough all the while borne up by wooden arches, some of them fixed in the ground very deep, and rising in height

above 23 feet: being brought to the intended cistern, on Michaelmas day, 1613, Sir Thomas Middleton, the brother of Mr. Hugh Middleton, being Lord Mayor, rode with many worthy aldermen to see the first opening of the river into the cistern. Sixty of the labourers were present with their tools, all habited well, and wearing green Monmouth caps; the foreman delivered a speech, which embodied in verse an account of the obstacles against which the projector had contended, and made honourable mention of the overseer, the clerk, the mathematician, the master of the timber-work, the measurer, the bricklayer, the engineer, the borer, and the pavior: after this was delivered, the whole went in procession to the floodgates, which when opened, allowed the stream to flow gallantly into the cistern, amidst the sounds of drums and trumpets. Wooden mains were at first laid down in the streets, and from them leaden pipes conveyed the water to the houses.

Stow also tells us that as early as 1580 a person of the name of Russel propounded to bring Istelworth or the Uxbridge river to London; and that by a geometrical instrument he laid this scheme before Lord Burgley, whom he told in his paper, "that he moved this not by skill or art of learning, which he did not profess, but only by an assured and infallibly grounded consideration taken by the difference of the height of the said Uxbridge river at the place or head appointed and the river Thames, right below the same towards Lalam; which was, he said, to be compared to the difference between the upper end of Holborn, which was a point of the new water, and Thames right against it below the Strand. Which thing rightly noted did show the easy possibility, and sufficient current to that place with discreet leading; for that the country lay well for that purpose, yet very dark, and seeming hard to all that took not with them the consideration aforesaid. So," added he, "it hath pleased God to bestow this blessing, and to appoint me an instrument, in a time best pleasing unto his will, showing that in all ages, neither power, wisdom, learning, or strength can perform an act until the time appointed, and the instrument to effect it." Lord Burgley was so pleased with the project, that "he drew with his own hand on Russel's paper the river and the town adjacent, describing the river Istelworth and another river, how they fell into Uxbridge river, and how that run by St. Giles."

In the year 1591, the same historian tells us, that Frederick Genebelli, an Italian, proposed to establish water-works in London, which should cleanse all the filthy ditches, and afford to the inhabitants a plentiful supply of wholesome water.

The works before alluded to, and first established at London Bridge by Peter Maurice, were erected near the first arch on the north side, after a lease had been granted him by the city. They consisted of a water-wheel worked by means of the tide; by this motion a number of force-pumps raised the necessary quantity of water to the top of a wooden building, where a cistern, elevated 120 feet, allowed it to flow by numerous leaden pipes into the dwelling-houses of Thames, Gracechurch, and New Fish Streets, as far also as the Standard in Cornhill: from the latter place it was again conducted by four other leaden pipes to Bishopsgate, Aldgate, the Bridge, and Wallbrook.

The highest point at which the water was delivered was the Standard in Cornhill; and the quantity thrown up by this first simple machinery of Maurice was estimated at 3,170,000 imperial barrels per annum, or an average quantity of 216 gallons per minute; the wheel working 16 pumps, each 7 inches in diameter, and having a stroke of 30. Machinery of a similar kind was put up in the other arches, and also on the Southwark side of the river, for the use of the inhabitants of that district.

Mr. Beighton, in the Philosophical Transactions, gives us some account of the state of these works as they existed in the year 1731. At that time the water-wheels which drove the pumps were placed under the arches of the bridge, and moved by the current of the stream; the dimensions were, 19 feet for the length of the axle, the diameter of which was 3 feet; there were eight rings to each, four arms, twenty-six floats, the length of which was 14 feet, and the depth 18 inches. These axles turned on two gudgeons in brasses, or two large levers, which were placed in a horizontal position, and therefore supported the weight of the wheel, which, by means of the levers, might be made to rise or fall with the tide in the following manner. The levers were 16 feet long, divided by the fulcrum at 10 feet from one end and 6 feet from the other. At the extremity was a sector or arc of a circle, described from the fulcrum of the lever, and to the bottom of this arch was fixed a long triple chain, similar to that of a watch; but the links were arched to a circle of 12 inches in diameter, with notches or teeth to take hold of the leaves of a pinion of cast-iron, 10 inches in diameter, with eight teeth, moving on an axis, fixed up over the arch at a considerable height; the chain went up to the pinion and turned over it. To the loose end of this chain was attached a large weight, to counterpoise the great weight of the water-wheel, which prevented the chain from sliding on the pinion. On the same axis as the pinion was a cog-wheel 6 feet in diameter, with forty-eight cogs. To this was applied a trundle or pinion with six teeth; and upon the same axis was fixed a second cog-wheel of fifty-one cogs, turned by a trundle of six rounds, on the axis of which was a winch or windlass. The other lever was provided with a similar chain and wheel-work; and the axis of the last mentioned trundle was prolonged until the two winches

nearly met, so that one man, with the two windlasses, raised or let down the wheel, as there was occasion, the quantity of water within his power to raise being fifty tons, which was more than the weight of the water-wheel.

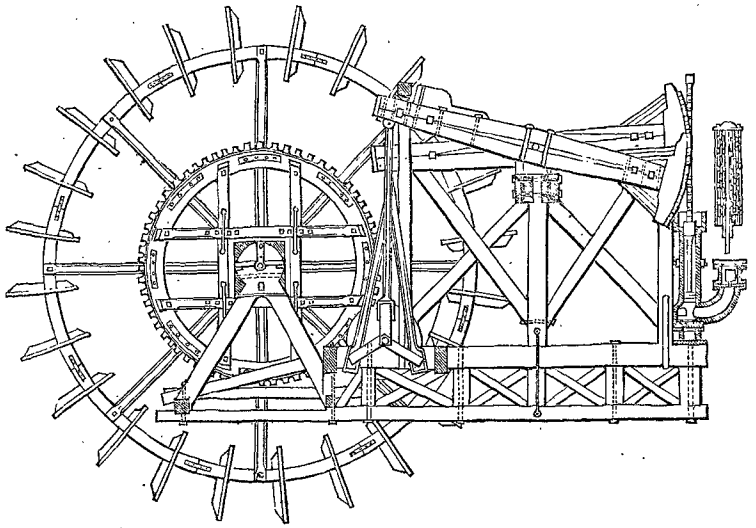


Fig. 538. WATER-WHEEL AT LONDON BRIDGE WORKS.

Near each end of the great axis of the water-wheel, a cog-wheel was fixed 8 feet in diameter, with forty-four cogs, working into a trundle of 4 feet 6 inches in diameter, and twenty rounds, whose axis or spindle was of cast-iron, 4 inches in diameter, lying in brasses, supported by strong timber framing at each end.

As the fulcrum of the levers was in the line of the axis of the trundle, in whatever situation the water-wheel was raised or let down, the great cog-wheel was always equidistant from the trundle, and worked and geared with it.

A quadruple crank of cast-iron was attached to the end of the axis of the trundle, the metal being 6 inches square; each of the necks was distant 12 inches from the centre of motion; the gudgeons of the cranks were sustained on brasses at each end, by two headstocks, fastened down by caps. One end of the axis was placed close to that of the axis of the trundle where it was 6 inches in diameter; at the other end was a slit: the crank terminated in the same manner, and an iron wedge was fixed one half into the slit at the end of the axis, and the other into that in the end of the crank, by which the axis turned the crank about with it. To each of the four necks of the crank was united an iron spear or rod, jointed at the upper end to its respective lever, and within 9 feet of the centre. The levers were 24 feet long, moving on centres in the middle of their length, and supported by the frame; at each end of each lever a rod was jointed, which descended into the pump-barrel, the forcers being fastened to it. Each end of the four levers worked a quadruple forcing-pump, which consisted of four cast-iron barrels or cylinders 4 feet 9 inches long, 7 inches bore above, and 9 inches below, where the valves were placed; the four barrels were fastened by screwed flanches over four holes in a hollow trunk of cast-iron, which had four valves in it; just over these holes, at the joining on of the bottom of the barrels, and at one end of the hollow trunk, was a sucking pipe and grate touching the water, which supplied all the four pumps alternately. To carry away the water which they forced out, there proceeded from the lower part of each pump-barrel a neck, turning upwards archways, whose upper part was cast with a flanch, to screw up to the under side of another square trunk, which received the necks of all the four barrels, which necks had bores of 7 inches in diameter, and over the holes in the trunk communicating with them were placed four valves at the jointings or flanches. The square forcing-trunk was cast with four bosses or protuberances, standing out against the valves, to give room for their opening and shutting; and on the upper side of the trunk were four holes, stopped with plugs, to take out when the valves required cleansing. One end of this trunk was stopped by a large plug, and to the other the iron pipes were joined by flanches, through which the water was forced up 120 feet, or to any height or place required. In addition to this four-barrelled pump, there was a similar one at the opposite ends of the levers. At the other end of the water-wheel

was placed work of a like kind, and; according to the calculation made by Mr. Beighton, the effect was as follows:—

In the first arch next the city was one wheel, with double work of sixteen forcers.

In the third arch there were three wheels, with fifty-two forcers, and one revolution of each wheel made two strokes and a fifth, so that one turn of the four wheels made 114 strokes.

When the river was in its best state the wheels went six times round in a minute, and but four and a half at middle water.

The number of strokes then in a minute was six times 114, or 684. The 2 feet 6-inch stroke in a 7-inch bore raising three gallons of water per minute, made the whole quantity raised in that time 2052 gallons, or in the day 46,896 hogsheads were raised to the height of 120 feet.

The power by which the wheels were moved was thus calculated:—the weight of the column of water on a forcer 7 inches in diameter, and 120 feet in height,

$7 \times 7 = 49$ pounds average in a yard nearly.
40 yards high.

1960 pounds in one forcer.
8 forcers always lifting.

15680 pounds, the weight at one time on the engine.

This is equivalent to seven tons weight: then as the crank pulls the lever 3 feet from the forcer, and 8·3 feet from the centre,

7 tons.
11·3

8·3)79·1(9·5 tons to the crank.

Wallower 2·2)9·5(4·3 tons on the trundle,
The spur-wheel 4

The radius of great wheel 10)17·2(1·72 tons.
20

The force of the floats 18 cwt. 14 lbs. 34·40 cwt.

But, to allow friction and velocity, may be reckoned at $1\frac{1}{2}$ tons.

The ladles or paddles, 14 feet long, 18 inches deep 22·4 square feet.
The fall of water sometimes 2·0 feet.

44·8
Contents in a cube foot 6 gallons.

268·8
Pounds to a gallon 10

112)2688(24 cwt.

The velocity of the water 4 feet in $21'''$ of time,

$21''' : 4$ feet :: $60'' : 685$ feet per minute.

The quantity expended on the wheel, according to the velocity of the stream, was 1433 hogsheads per second, and the velocity of the wheel was to the velocity of the water as 1 to $22''$.

In the year 1767 it was discovered that the supply of water was diminished to 2716 hogsheads in the twelve hours. Mr. Smeaton was employed to make some improvements, and he placed a machine in the fifth arch, considerably larger than either of the others.

	Ft.	In.
The diameter of the water-wheel to the extremity of the floats	32	0
The diameter of ditto in the rings out and out	27	0
Width of the wheel or length of floats	15	6
Number of floats twenty-four, width of each	4	6
Diameter of spur-wheels	14	0

Number of cogs eighty, number in the lantern twenty-three. Diameter of the water-wheel gudgeons 7 inches, and the length of the cylindrical part 7 inches.

When the tide was low the water was forced up by the aid of a fire-engine, as they were

then called, to the top of the tower, 120 feet high, and in this condition the works remained until the parliamentary inquiry of 1821, when it appeared that 29,516,333 hogsheads of water per annum was supplied to 32,071 houses, which paid a rental for the same of 35,358*l.*

Smeaton also erected an atmospheric engine of ten horse-power to assist the wheels at neap tides.

It is greatly to be regretted that no arrangement was then or has since been made by the proprietors of small tenements for supplying their tenants with water; there is a natural objection on their parts to pay the usual demand of the companies, which to them would be a considerable item; but if it were rendered imperative that every small dwelling should be supplied, there can be little doubt that the companies would lessen their charge, and the landlord would be indemnified by an increased rent of a few shillings, which would not be felt by the occupants; and efficient drainage for the surplus should also be provided. The increasing luxuries of the middle classes require this attention to the necessities of those who compose the next grade in the social system, and it is surely not too much to ask for them the means by which the first claim to personal respect, cleanliness, can be secured, and without which frequently the intellectual and moral health is ruined.

Minor works were established during the seventeenth century for the supply of various districts: the Merchants' Waterworks had a windmill in Tottenham Court Fields, an overshot wheel worked by the common sewers in St. Martin's Lane, and another by that in Hartshorn Lane. Each of these had 6-inch mains, from which smaller pipes branched off to the neighbouring houses.

At Shadwell, a horse-wheel was put up in the year 1660, and two atmospheric engines were subsequently erected, which drew water from the Thames, and supplied it to the inhabitants of that district through two mains of 6 inches in diameter. To the original projector succeeded a company, which was incorporated in the reign of William and Mary. Two of the earliest manufactured engines by Bolton and Watt were put up at these works, and in the year 1808 they were purchased by the East London Company.

The York Buildings' Water-works were established at the bottom of Villiers Street, in the Strand, in the year 1691. A horse-wheel was first employed to pump up the water from the Thames; one of Savery's engines was afterwards introduced, for which one of Newcomen's was substituted. About 1804, the company erected an engine of 70 horse power, took up all the wooden pipes that had been previously used for the distribution of water, and laid down cast-iron. Newcomen's engine is said to have raised daily 356,000 gallons to a height of 102 feet, or 3,137,000 barrels per annum.

West Ham Works, established in the year 1743, obtained their water from the river Lea by means of a fire-engine of 6 horse power; they now form a portion of the East London.

The Banks-end Works, in Southwark, or Old Borough water-works, were founded in the year 1756; and when London Bridge was rebuilt were purchased by Mr. Edwards, and became the foundation of the present Southwark Water Company. Other works were established at Rotherhithe, where a wheel was turned by the tide water collected in the ditches, and at Lea Bridge, which were called the Hackney water-works.

The Lambeth Water-works were established in 1785, and in 1805 the South London were commenced.

At present the metropolis is chiefly supplied with water by the New River, the Chelsea, the Grand Junction, the West Middlesex, the Southwark, and the East London Water Companies. The power made use of is universally the steam-engine; and if we consider what is effected by the most economical of these engines, we shall not be surprised at the quantity daily distributed in London. Taylor's engine at the United Mines is said to have raised, in 1841, 92,500,000 pounds weight of water 1 foot high by each bushel of coal consumed, and in the following year nearly 100,000,000. The bushel of coals weighed 94 pounds, so that a pound of coal raised 1,000,000 of pounds, or 16,000 cubic feet of water, 1 foot high. It would require either a man to labour $4\frac{1}{2}$ hours or a horse $\frac{3}{4}$ of an hour to perform the same quantity of work as a pound of coal so applied.

The New River Company is now the oldest remaining in the metropolis; to it was transferred by an act of parliament the London Bridge water-works, when the old bridge was demolished. This work, projected and carried out by one individual, Sir Hugh Middleton, as before observed, was commenced by an open canal 40 miles in length, into which was collected various springs which rise near Ware and Amwell, in Hertfordshire. The distance of these springs from the metropolis is not more than 20 miles in a straight direction, but the circuitous way by which they are conducted was preferred in order to obtain a fall of 3 inches per mile throughout their whole course.

The timber aqueduct over the valley at Bush Hill, 660 feet in length, was removed in the year 1785, and an earthen embankment substituted in lieu of it; the same change has taken place with the open wooden trough at Hornsey and other places. After the water has arrived at Stoke Newington, it is conducted for more than 200 yards by a subter-

raneous tunnel; at Islington its width is about 14 feet 6 inches, and its average depth 4 feet 6 inches. Two hundred bridges were constructed in its varied course for the convenience of the proprietors of the adjoining lands. The supply from the Hertfordshire springs being found inadequate to the demand of the company, a considerable addition was obtained from the river Lea, on the banks of which is a sluice; and in order that the guardians may know what quantity to let out, a guage is fixed across it, composed of a large stone, under which the water flows out in a regular manner.

The first distribution of water, as we have seen, was by leaden pipes, which abundantly supplied the conduits in various parts of the city; these were mostly destroyed during the great fire; from them the inhabitants received their several quantities by the aid of water-carriers. After the destruction of this system, a new arrangement was made to lay the water on to the houses, and this was admirably accomplished by wooden pipes or mains, of elm timber, and at the end of the last century, when they were removed to make way for iron, the New River Company had upwards of 400 miles of wooden pipe.

When water-closets were more generally introduced at the commencement of the present century, a more abundant supply of water was required, which was first poured into the cistern, usually placed in the basement, from whence by means of force-pumps it was thrown into the tank to feed the closet; this system was afterwards further improved by supplying water at a higher pressure by the use of steam-power, and which could be more easily effected through the introduction of iron pipes. Twenty miles per annum of wooden pipes, 6 or 7 inches bore, with their 3-inch service pipes, were annually removed until the whole of the districts supplied by this company were furnished with cast-iron mains; these vary in diameter from 1 to 3 feet, and the services are generally 4 inches.

When the iron mains were first laid down, they were supposed to impart a chalybeate quality to the water, and they were in consequence dressed in the interior with a preparation of lime-water, which entirely removed the evil. They were screwed together at the joints, which prevented their free expansion and contraction, and often occasioned them to be broken by the varied temperature of the water, rendering them very defective in the winter season. Cylindrical socket joints were then introduced, and the pipes cast in lengths of 9 feet, which entirely obviated all inconvenience. These joints being accurately turned in a lathe no stuffing is required; a little whiting and tallow is used, and they are at once formed and the pipes driven up; joints so made answer well to a suction pipe of a steam-engine 30 inches in diameter.

The tenant's communication pipes are united to the mains by flange joints, which are cast with the pipes, and all the cross branches are slightly curved, which materially reduces the friction to which they were subject when lying at an angle. Screw cocks have also taken the place of the valve-cock, so that the water is now gradually shut off, and not as formerly in an instant, which frequently occasioned the bursting of the pipes. At the New River head, Pentonville, there are two powerful steam-engines as well as an engine for forcing the water to a higher reservoir near the works, and another near Tottenham Court Road.

The works are about 85 feet above the level of the Thames, and all the houses above this were formerly supplied by a windmill, afterwards by a horse-mill, then by a fire-engine, and in 1820 by three steam-engines of 63 horse power. Mr. Mylne, the engineer to the company stated, in the year 1844, when he gave his evidence to the Commissioners of Inquiry into the State of Large Towns, that the average annual quantity of water supplied for the last three years had been 614,087,768 cubic feet: deducting from this the larger consumers, and street watering, amounting to about 33,529,400 cubic feet, there would remain 580,558,368 cubic feet per annum, equal to 46½ cubic feet per tenement each alternate day; the number of tenements supplied being 81,555.

Chelsea Water-works were established in the year 1724: about two years afterwards the basin in the Green Park was built for the supply of Whitehall, and another for Westminster in Hyde Park. The water was at first obtained from the Thames by means of a wheel throwing it into settling ponds, which was worked from other ponds in the same manner as a tide mill, and in the middle of the last century 1700 tons of water were so raised daily, which not being adequate to the increasing demand, the works were enlarged, and about the year 1810, they were removed from the site which now forms the Belgrave basin to their present situation. They occupy nearly 7 acres of land; the water was originally obtained from a dolphin, which stood about 50 feet from the bank; this was a brick structure below, and iron above, into which the mains entered, and drew their supply; but being situated near the mouth of a large sewer, it was removed, and the main pipes are now supplied from the Surrey side of the river; the water is received into settling reservoirs, lined with stone and brick, the first of which is 100 feet in length, 70 feet in width, and 10 feet in depth; from thence it is forced up into one 300 feet in length, 160 in breadth, beyond which is another, 540 by 140 feet; from these the water flows into two filters constructed below them, one of which is 240 by 180 feet, and the other 351 by 180 feet.

The mode of filtration is by the descent of the water, which, in its way, is made to pass through fine and coarse river sand, broken shells and pebbles, and small and large gravel. These several materials are laid in a reservoir, disposed in ridges, which show an undulated surface; and the whole depth of the beds is about 5 feet. The upper layer is fine sand, the second coarse sand, the third pebbles and shells, the fourth fine gravel, and the fifth large gravel; built within these with cement blocks are eleven brick tunnels for collecting the filtered water, partially open-jointed, with spaces of 1½ inch on the bed, with the heading joint of each brick also open.

The bed of the filtering works consists of loam, sand, and gravel, which overlie the London clay to the depth of 30 feet; the two latter strata contained powerful land springs, so that it was necessary to form a bottom with clay and cement walling. The bed covers an area of an acre, and there is an elevated reservoir of nearly the same size.

The water is let in by nine brick tunnels, and the ends of the pipes are fitted with curved boards to diffuse the currents of water, and prevent the surface of sand from being disturbed; this is scraped every fortnight, and from a careful examination, it appears that the sediment penetrates to the depth of from 6 to 9 inches, to which depth the sand is frequently removed, and fresh supplied by carefully lifting portions in succession. The quantity of water filtered is from 300,000 to 400,000 cubic feet daily, or 2,300,000 gallons. The cost of the filter, exclusive of the land, was 11,700*l.*, and the annual expenditure for raising the water on the filtering bed is 800*l.*, for cleansing and renewal a similar sum. A steam-engine of 120 horse power raised, in the year 1834, 4,640,000 gallons of water per day, a portion of which was carried to the height of 135 feet: 13,892 houses were supplied in the year with 15,750 hogsheads of water.

The West Middlesex Water-works were established in the year 1806, and are situated on the banks of the Thames at Hammersmith; they obtain their supply by means of steam-engines, the power of which is equal to raising 6,000,000 gallons per day to the height of 122 feet; the water is pumped into a reservoir at Notting Hill, and another at Primrose Hill.

The number of houses and buildings supplied are 16,000, and the total quantity of water annually is 20,000,000 hogsheads; the average daily consumption 2,250,000 gallons, or about 360,000 cubic feet. This company supplies that part of the metropolis which lies west of Tottenham Court and Hampstead Roads and the north of Oxford Street, the Edgeware Road, the Regent's Canal, Bayswater, Kensington, Hammersmith, Fulham, and Chiswick.

The Grand Junction Water-works, established in the year 1810, are situated at Chelsea, and at first derived their waters from the Thames, with which they filled three reservoirs at Paddington; at present they are empowered to draw their supply from the same river, at a little above Kew Bridge, on the Surrey side. A steam-engine, of 500 horse-power, drives the water through a main, 30 inches in diameter, for a distance of 6 miles, to Paddington, where it is subjected to filtration. The total quantity supplied annually was 21,702,567 hogsheads to 7,700 houses; the daily consumption being estimated at 2,800,000 gallons, or upwards of 450,000 feet. The highest elevation is 151 feet 9 inches, and the average quantity raised per day 3,744,213 gallons. This company supplies the district included within Oxford Street, Princes Street, St. James's Park, Hyde Park, the Edgeware and Uxbridge Roads, and the Regent's Canal. After making due allowance for watering the streets and waste, the average consumption of each house, when Mr. Telford made his report, was estimated at 180 gallons per day, or 25 gallons per day for each person.

Southwark, and the south side of the Thames is supplied by the Lambeth, the Southwark Companies, and the Vauxhall or South London.

The Lambeth Water-works are upon the Thames, between Westminster and Waterloo bridges; they have no reservoirs, the water being forced immediately from the river into the mains, and thence distributed to about 16,000 tenants, who consume about 1,244,000 gallons daily, or nearly 200,000 cube feet.

The Southwark Water-works are upon the banks of the Thames between Southwark and London bridges, and take their supply from the middle of the river opposite their engines; 7000 tenants receive about 720,000 gallons of water, or 115,000 cubic feet, daily.

The Vauxhall or South London Water-works are in Kennington Lane, and have an engine on the river at the foot of Vauxhall Bridge; they obtain the water from the Thames, and have reservoirs for the service of their upper engine. They supply about 10,000 tenants with about 1,000,000 gallons daily, or about 160,000 cubic feet.

Each of these establishments has two engines; the aggregate power of the six may be estimated at about 235 horses; the whole of the water furnished amounts to nearly 3,000,000 gallons, or 485,000 cubic feet daily, which is distributed among 33,000 tenants.

East London Company, established in the year 1807, and situated at Old Ford, on the

river Lea, a little above Bow Bridge, draws its water from above the influence of the tide, and is carried by an aqueduct into settling reservoirs, which are upwards of 18 acres in extent; it then flows into another, from which it is pumped up by steam-engines of sufficient power to throw up 11,293,776 gallons per day: the highest elevation is 107 feet. In the year 1820 the total quantity supplied annually was 29,516,333 hogsheads; and the company had laid down in the streets 400 miles of iron pipes, one half of which were in use at one time. When the water is at rest any matter mechanically suspended in it settles in the pipes, to avoid which, before the turncock gives the supply to any street, he starts the end plug of the service for three or four minutes, and lets a part of the water run out, which removes the deposit. The number of houses served is 50,000, and there are as many tanks and waterbutts in the district in addition.

It may be well to remark, that the quantities given are not to be considered as fixed, they are necessarily daily increasing; but in the year 1826 the total annually distributed to the metropolis by these public companies amounted to 155,381,038 hogsheads, the number of houses being 120,000, and the rental paid for the same 175,890*l.* The daily supply is stated to be equal to the contents of a lake of 50 acres, 3 feet in depth.

Trent Waterworks, at Nottingham, were established in the year 1830, under the direction of Mr. Thomas Hawkesley; 8000 houses are supplied by this company, and the expenditure was about 30,000*l.*; the water can be thrown to any level; the annual average charge is 7*s.* 6*d.*, and the quantity supplied to each house is about 80 or 90 gallons per day, at a cost of not much more than a farthing. The greatest pressure at which the water is kept upon the pipes is about 120 feet, but the average is not more than 80 feet. The pipes are charged so as to deliver water to the tops of all the houses within a proper distance of the superior reservoir: they are generally ½ inch in diameter, and each foot in length weighs 2¾ pounds.

It has been estimated by Mr. Hawkesley that the company sell 1000 gallons of water at something under 3*d.*, and that the total or general charges, exclusive of the interest on capital, amounts to 1·42, or a little less than 1½*d.*; this is made up by a charge of ¾*d.* upon the quantity for salaries, taxes, rent, repairs, &c., another ¼*d.* for attendance upon the machinery, and a trifle less than ½*d.* to defray the cost of coals, hemp, leather, oil, tallow, repairs, &c.

The construction of the filter is thus described:—the reservoir, which lies on the banks of the Trent, about a mile from the town, is excavated in a natural stratum of clean sand and gravel, through which the water slowly percolates to a distance of 150 feet from the river. The adventitious solid matter is generally deposited on the bed of the river, from which it is washed away by the action of the stream. The river at times is exceedingly thick, and of the colour of tea, from the admixture of peat and other vegetable matters; but after filtration through the bed, the water becomes perfectly pellucid.

The reservoir being exposed to the action of the sun produces vegetation of the conferva genus, which is removed at intervals of about three weeks in summer, and six weeks in winter, by pumping out the water and the use of the broom; after which operation a pin may easily be distinguished at the bottom, a depth of 9 feet. To prevent the small communication pipes from being choked by the accidental introduction of leaves and other extraneous substances, the water is drawn through large sieves of fine strainer cloth. In addition to the reservoir there is a filter tunnel, passing through a similar stratum for a considerable distance up the adjoining lands, 4 feet in diameter, and half a brick thick, and being laid without mortar or cement cost only 10*s.* per foot, including an excavation to the depth of 12 feet.

Greenock Water Supply, under the direction of Mr. Thom, engineer. A company incorporated by an act of parliament in the year 1825 undertook these works, and the reservoirs they have formed contain 310,000,000 cubic feet of water, into which annually drains more than double that quantity; their capacity is calculated for the consumption of more than six months.

There is above the town a filter, the basin of which contains one day's supply of water to the inhabitants; the conduit pipe is 15 inches square, perfectly water-tight, being of stone built with cement; the cost was one-third of that of an iron pipe of equal capacity. In it cesspools are formed, into which some of the sediment is deposited in its course before it enters the three filters. Each of these are 50 feet in length, 12 feet wide, and 8 feet deep, and the water percolates through them either upwards or downwards at pleasure. When it passes downwards, and the lodgment of the silt is considerable, by shutting one sluice and opening another, the water is made to pass upwards with sufficient force to carry the sediment with it into a waste drain. After this is cleansed, the sluices are again changed, and the filter operates as before.

By this arrangement of the several beds, a return current of water may be forced upwards, and thus cleanse them from the deposit; there is also less average pressure and

pumping required, and the cost of cleansing is lessened materially. The return of the water upward cannot, however, entirely remove all that has been previously lodged, nor can it serve the purpose of so effectually cleansing as to obviate the necessity for renewing the several materials. Experiment has shown that, when the upward current is applied under a pressure of 26 feet head, it does not remove one-tenth part of what has been deposited: it seems necessary to produce great agitation between all the particles before the impurities will detach themselves from the grains of sand.

Impurities usually found in Water, are the mineral or saline, the vegetable, the animal, and mechanical. The saline are earthy salts, salts of lime, and salts of magnesia; common salt is also usually present, and sometimes bicarbonates of soda and potash. The most important of the earthy salts is the bicarbonate of lime. The whole saline matter consists of two portions, the neutral and the alkaline. The latter are entirely bicarbonates, as those of lime and magnesia, to which sometimes are added those of potash and soda. The neutral portion consists of the neutral salts, of earths and alkalies, such as gypsum and common salt. Salts of iron are sometimes found, giving an inky taste to the water, and a yellowish tint to linen washed in it.

The earthy salts and iron salts are the principal cause of *hardness*, which effect is often also produced by an excess of carbonic acid, at least when it is in a greater quantity than is sufficient to form the bicarbonates present.

Filtration has no effect upon the hardness of water, but it is softened by exposure to the air, and sometimes by the process of boiling, when the earthy bicarbonates are decomposed. The New River water contains, according to Mr. Clark's evidence, given before the Commissioners of Inquiry into the State of Large Towns, 13 grains or more of carbonate of lime in every gallon. In the middle of May, water taken from the Thames at Mortlake contained 14 grains, that from the East London Waterworks upwards of 16 grains, that of the Vauxhall Company, on the Surrey side of the river, 13 grains.

Thomas Clarke's, M.D., Process for Purifying Water.—To understand its nature, it is necessary to advert to a few chemical properties of the familiar substance chalk, which at once forms the bulk of the impurity that the process will separate from water, and is the material whence the ingredient for effecting the separation is obtained. In water chalk is almost or altogether insoluble; but it may be rendered soluble by either of two processes of a very opposite kind. When burned, as in a kiln, it loses weight: if dry and pure, only 9 ounces will remain out of 16; these 9 ounces will be soluble in water, but they will require not less than 40 gallons of water for entire solution. Burnt chalk or quicklime, when held in solution, forms lime-water, which is perfectly clear and colourless. The 7 ounces lost when the chalk is converted into lime is carbonic acid gas. The other mode of rendering chalk soluble in water is nearly the reverse. In the former mode, a pound of pure chalk becomes dissolved in consequence of losing 7 ounces of carbonic acid. To dissolve in the second mode, not only must the pound of chalk not lose the 7 ounces of carbonic acid that it contains, but it must combine with 7 additional ounces of that acid.

In such a state of combination chalk exists in the waters of London, dissolved, invisible, and colourless, like salt in water. A pound of chalk dissolved in 560 gallons of water by 7 ounces of carbonic acid would form a solution not sensibly different in ordinary use from the filtered water of the Thames in the average state of that river. Chalk, or carbonate of lime, becomes a bicarbonate when it is dissolved in water by carbonic acid. Any lime-water may be mixed with another, and any solution of bicarbonate of lime with another, without any change being produced; the clearness of the mixed solutions would be undisturbed; not so, however, if lime-water be mixed with a solution of bicarbonate of lime. Very soon a haziness appears, this deepens into a whiteness, and the mixture soon acquires the appearance of a well-mixed whitewash. When the white matter ceases to be produced, it subsides, and in process of time leaves the water above perfectly clear; the subsided matter being nothing but chalk. What occurs in this operation will be understood, if we suppose that 16 ounces of chalk, after being converted by burning into 9 ounces of quicklime, is dissolved, so as to form 40 gallons of lime-water; that another 16 ounces is dissolved by 7 ounces of extra carbonic acid, so as to form 560 gallons of a solution of bicarbonate of lime, and that the two solutions are mixed, making up together 600 gallons. The 9 ounces of quicklime from the 16 of chalk unite with the 7 extra ounces of carbonic acid that hold the other 16 ounces of chalk in solution. These 9 ounces of quicklime and 7 ounces of carbonic acid form 16 ounces of chalk, which being insoluble in water become visible at the same time that the other pound of chalk, being deprived of the extra 7 ounces of carbonic acid that kept it in solution, reappears. Both pounds of chalk are found at the bottom after subsidence. The 600 gallons of water will remain above clear and colourless, without holding in solution any sensible quantity either of quicklime or of bicarbonate of lime.

The weight of chalk separated from the whole waters with which the several companies in London supply the public annually is estimated by Dr. Clarke to be equal to 9000 tons, and that to purify it after the above method would cost only 10*l.* per day.

Few subjects have more perplexed the civil engineer than the theory of filtration, and many thousand pounds have been uselessly expended to obtain pure and wholesome water. The two processes generally adopted are, first, either that which acts entirely on the surface, in the same manner as passing water through filtering paper, or by a layer or number of layers of various qualities of sand or other material.

By the first of these methods minute impurities may be retained, and as the filtration proceeds, the quantity of water that passes is comparatively small; its passage is gradually lessened by the deposit of impure matter upon the filtering surface, and the pores through which it passes become stopped. By the second the sand is usually selected of different sized grains, and the mud or foreign matter which the water holds mechanically in the course of time fills up the vacuities that exist between the particles, destroys its porous quality, and prevents its use as a filter. Water passing through sand, therefore, deposits its impurities between the grains, and if these are not frequently changed, the mass will become impermeable, and cease to do the work required. Such a filter would therefore answer admirably for a short time, or until the whole of the interstices were closed, and experiment has proved that the quantity of water passed through diminishes each succeeding week. A filter should be so constructed, that the material used should be unchanged, imputrescent, and without any alteration in its mechanical structure, allowing the water at all times to pass freely.

M. Maurras's system of filtration is effected by means of a water-tight iron box, about 5 feet 6 inches square, with a filtering surface within it equal to 60 superficial feet, which, with a 12 feet 6 inches head of water, it is calculated will filtrate 150,000 gallons in the space of 24 hours.

The water is introduced at the top, and makes its exit at the bottom, after having passed through several layers or beds of coarse and fine sand; it at first percolates a coarse sand, which lies both at top and bottom, then a fine sand, and afterwards meets in the centre of the box, where it makes its exit.

The principal part of the arrangement, however, consists of a number of horizontal closed iron boxes, the upper and lower sides of which are pierced with small holes, for the passage of the water under pressure: these are placed one over the other, and between them are alternate layers of coarser and finer sand, through which the water is first made to pass; they are tightly packed with riddled sand, which cannot escape through the fine holes made for the passage of the water, in consequence of its large grain, whilst its interstices are sufficiently small to allow the finer sand of the filtering beds between the boxes to enter and be retained, and although that of the smallest grain has been used under a pressure of a column of water of 60 feet, it has been found that none has escaped.

The machine is cleansed by reversing the current of the water, which, by an arrangement of sluice cocks, is effected very easily; when the water is admitted at bottom and forced upwards, a violent agitation takes place throughout the pores of the sand, and the accumulation of deposited matter is thoroughly dislodged and carried away.

The filtering sand, of various degrees of fineness, cannot escape, and can be changed at pleasure.

In most parts of England water is obtained from wells, some of which are Artesian. Of the quantity of water which descends in rain in our latitude, one-third has been estimated as passing off by evaporation, the remaining two-thirds being required for the support of animal and vegetable life, and to supply the subterraneous springs. Rain water either runs off upon the surface or percolates the strata, being received in the fissures or vaults of the earth, where it forms subterraneous reservoirs.

Where beds of gravel rest upon a substratum of clay, the lower portions contain water; if the clay is thin, and has fissures or openings in it, the water passes through, and continues to descend till it meets some other layer, which will retain it.

Some wells are supplied by water descending in the strata, others by its ascent from below by means of hydrostatic pressure, which is the case with Artesian wells, or perpetually flowing springs: these are numerous in the neighbourhood of London, where they are formed by penetrating the chalk or the plastic clay formation. At Sheerness, the sandy strata of the plastic clay formation was reached after boring through the London clay 330 feet, and in many districts the chalk has been pierced to a considerable depth beneath the clay, and abundance of water obtained, which is generally perfectly clear and bright, for by its passage through the various strata, it is deprived of all that it held mechanically, as well as other impurities, which are taken up by one earth or the other.

The district called the London Basin may be considered as a continuous seam of chalk, varying in thickness, and sometimes covered with sand and gravel alternating with plastic clay, over which is a thick stratum of London clay. Under the chalk basin is a substratum of clay, through which water will not pass, and consequently a large supply is always to be found in it. The surface of the water in this subterranean reservoir does not stand at one uniform level, but rises in a distance of 14 miles, as between Watford and the highest spring in the chalk hills, as much as 300 feet. The molecular attraction of the particles of chalk

through which this sheet of water is spread, and the obstruction presented by friction to its descent, may in some degree account for its inclined position, though on the other hand it appears, that when the floods at Watford affect the wells in that neighbourhood, the same influence extends to those in London a few hours afterwards; and a steam-engine employed to pump water from a well near Watford lowers that in all the wells to a considerable distance around it.

The Reverend J. C. Clutterbuck has shown that if a line were drawn from a point 3 miles south of the Colne at the level of that river, which is 170 feet above Trinity high water-mark, to the mean tide level in the Thames below London Bridge, the dip would be 180 feet in 14 miles, or an average inclination of 13 feet in each mile; the uniformity of this inclination is proved by the wells at Hendon union workhouse, Cricklewood, and at Kilburn, in which 20 years ago the water stood much higher than at present, the exhausting of the wells in and about London by means of powerful machinery having reduced its level considerably. The level at which the water stands in the chalk is subject to periodical change; there is also another supply to that portion of the London Basin beneath the plastic clays, which is not fed by infiltration, but probably by means of hydrostatic pressure from higher sources.

This periodical change observed in the height of water in the chalk, is called the oscillation of the water level, and is caused by an irruption of rain water, which finds its way from the surface of the London and plastic clays into the chalk through fissures, and at last arrives at the sand above the plastic clay formation.

The water level line generally inclines about 10 feet in a mile when most depressed, and after heavy rains, when the clays throw their water from their surface, the irruption of the water may be seen at the outcrop of the sand of the plastic clay formation; the level will then be raised in proportion to the quantity of water which passes through the sand into the chalk beneath it, the elevation of level extending towards the Colne, in a ratio increasing with the distance from the river; the fixed summit will remain unaltered, until the level at the point of irruption has attained an elevation at which the water can flow towards the south. After a period of dry weather, the level will decline in the same ratio as it has risen until it regains the original level with a regular inclination.

The same effects may be observed in all chalk districts where no streams are found on the surface; the valleys which lie between the rounded hills seldom exhibit any running water, but wherever wells are sunk and the water-bearing stratum is arrived at, an abundant supply may be obtained. Taking the level of the water in the wells on the highest ridge, and drawing from thence a line to the surface of those found in the lowest, or that of the river into which they drain, we find that the surface of the water of all the intermediate sinkings corresponds with the slant line of drainage within the chalk, and if by means of pumping or tunneling, we exhaust the water on any part of this line, all the supplies above are affected. In whole districts the wells have by this means been rendered dry, and it is only by sinking them deeper, or out of the influence of such effects, that water can be again obtained.

Canals. — Where rivers abounded with shoals, we find it a very early custom to contract the channel, and thus obtain deep water, or sufficient to float small vessels. Another mode, called *flashing*, was applied to shallow streams, and consisted in penning up for a time the river itself within reservoirs, which had openings cut in them, to allow of the passage of boats.

Wears and sluices were made use of when the rise in the bed of the river was considerable; there was an opening in the wear, closed by a flood-gate, which allowed the passage of vessels: this commonly consisted of two abutments of stone, projecting from each bank, in which was a groove to receive a plank, or timber, which was let down and drawn up at pleasure; or a sill was laid at the bottom, with a groove, into which perpendicular planks were dropped, and maintained at top by one or two strong horizontal timbers, resting on the abutments. To open this it was necessary to draw out one plank or paddle at a time, and then remove the horizontal timbers; after the boat was hauled through, the whole was replaced, and the water in the head or reservoir again permitted to rise.

Inclined planes and rolling bridges were also in use for transferring boats from one pond to another across a wear.

We have already seen that in Italy, France, Holland, and Germany, canals were established at a very early period, and it is remarkable that we do not find much attention paid to the subject in England, until about the middle of the sixteenth century, when it was proposed to render the Isis and Avon navigable by means of *sasses*, and then to unite the two streams by a canal of about 3 miles in length; but nothing of importance was undertaken until James Brindley connected Liverpool with London, Bristol with Hull, and several other districts by canals; he was a native of Tunstal in the parish of Wormhill in Derbyshire, and the date of his birth is said to be about the year 1716. He served his apprenticeship to a millwright at Macclesfield, where he acquired a thorough knowledge

of his business as practised at that time. For some years after he was employed in making improvements in the machinery of several mills in Cheshire and Lancashire, where he gave considerable satisfaction to his employers. About the year 1758, the Duke of Bridgewater turned his attention to the subject of inland navigation, and petitioned parliament to grant him permission to cut a canal; having previously observed some of the most important on the continent, he was desirous of benefiting from their introduction into his coal-fields in South Lancashire. The Duke, having obtained his act, employed Brindley to execute a canal from Worsley to Manchester, a distance of 10¾ miles. This is the first canal of any importance in England, and the skill displayed in carrying it over the river Irwell by an aqueduct at Barton excited much astonishment at the time. This aqueduct consists of three semicircular arches, one in the centre being 63 feet span, and 39 feet in height above the river; it is entirely built of dressed stones, and the channel for the water is puddled at the sides to prevent leakage. Across the meadows at Stratford the canal, which is 24 feet in breadth at top, is carried on an embankment, 900 yards in length, and 17 feet high, with a breadth at the base of 112 feet, the slopes being two to one.

Legislation relative to rivers and canals.—There is no general administration to regulate water conveyance: the whole management of this important branch of commerce is either under the control of municipal authority or special commissioners chosen by virtue of acts of parliament from among the inhabitants of the various districts to which the water transit belongs. We find that at an early period of our history the navigable rivers throughout the kingdom were considered as contributing to the advantages of trade, and every means were adopted to prevent private individuals from appropriating them to their own use. In Magna Charta, cap. 16., a clause is inserted, making the course of the Thames and all other rivers free of duty to those that navigated them, and enacting that any obstructions to the transit should be removed.

In the reign of Edward the Third a special act was made (1351) to demolish all dams which impeded navigation, without allowing any compensation to the owners or persons who had constructed them. Twenty years afterwards another act was passed, ordaining that a fine of 100 marks should be paid by any individual who injured the navigation of the rivers.

In 1427 (6 Henry 6th, ch. 5.) commissioners were appointed for the management of rivers, either for the purposes of internal navigation or drainage, the removing of any obstructions in the streams, and preventing inundations. By this act the chancellor nominates commissioners to superintend the repairs of all dykes, bridges, roads, and the damage done by natural or artificial streams of water. They have the right to construct any works, to destroy any ponds, dams, or mills, or reclaim land, and institute inquiries or actions at law, on account of injury to any water-conveyance; with the power of fixing the amount of fines according to the damage sustained, of levying taxes for the execution of the several works on the property which is to be benefited; and the law enjoins perfect equality in the territorial tax, without any exemption to either the church, the nobility, or the king.

Individuals refusing to pay their portion of the tax are liable to have their property confiscated; or the commissioners may seize the land of any one refusing, and let it at a life-rent or for a term of years. They may put in requisition horses, waggons, oxen, and workmen, by paying suitable wages, and may take any timber requisite at their own estimate of its value. The commissioners appoint bailiffs, collectors, treasurers, and superintendents, who are answerable to them, and whose salaries they fix.

Commissioners, previous to taking the necessary oath, must show that they are possessed of a clear annual income equal to forty marks, or landed property to the value of 100*l.*, or that they are freemen of a city or an incorporated borough, or members of one of the four principal Inns of Court.

When any seizure is made by order of the commissioners the party may prosecute the agent executing the order, and a jury then decides upon the question according to law. If the agent gain the cause, he receives triple the amount of the expense of the action.

There are besides several special laws for the management of currents of water. In the year 1423 (Henry 6th) a committee was appointed to examine the course of the river Lea, and to render it fit for the purposes of navigation. In the following year, the parliament authorised the chancellor to select a committee out of the adjoining parishes, who were qualified to correct the defects of the river, by the execution of any works, or the removal of anything which impeded the navigation (3 Henry 6th, cap. 5.).

The river Thames is under the direction of the mayor and corporation of the city of London, who, as conservators, have the management of all that regards the navigation, from the mouth of the river to as high as the flood tide extends, (4 Henry 7th, cap. 15.). They also exercise an inspection over all stagnant waters and currents which communicate with the Thames. One half of the fines paid by persons convicted of having in any way damaged the banks or injured the bed of the Thames goes to the city of London, (27 Henry 8th, cap. 18.).

Parliament gave to the corporation of London (13 Elizabeth, cap. 18.) the right of rendering the river Lea navigable from Ware to the Thames.

In the 21st year of James the First, cap. 42., a very important act was passed, which had for its object the diminishing the price of fuel and other articles of necessity in the city of Oxford; to facilitate the conveyance of produce to Oxford, and to prevent the high roads which conducted to that city from being broken up during the winter. These works were consigned to the superintendence of eight commissioners, four of whom were to be appointed by the city, and four by the university.

Various other acts of parliament have been made to protect the works necessary for water conveyance, (1 George 2nd, cap. 19. sect. 2. and 8 George 2nd, cap. 20. sect. 1.).

In the reign of Charles I., Vermuyden, a Dutch engineer, was authorised to drain the land at the mouth of the Trent, which was performed in 5 years, at an expense of £55,825, and to him may perhaps be attributed the introduction of the first lock in England, which is on the river Idle, and called Misterton Sas: after the Restoration inland navigation appears to have received increased attention, which may, in some measure, be attributable to the opportunities afforded the exiles in the Low Countries of seeing the great advantages to be derived from facility of communication; but it was not until the commencement of the eighteenth century that this important object was conducted upon any thing like principle.

Previous to the commencement of this century, various acts of parliament were passed, relating to the improvement of the navigation of different rivers, either by straightening, widening or deepening their channels, forming banks with towing paths, as well as jetties and sluices, penning up water, and making flushes to overcome the rapid part of the streams or the shallows. This was accomplished by pound locks, which were necessary where mill-weirs were established, as the boats could not make their ascent or descent without, for in all the acts of parliament special care was taken of the mills.

In 1776, in order to overcome all the difficulties attendant upon the use of the natural streams, a separate cut with pound locks was made from the Mersey by the proprietors of the Sankey navigation, who had previously obtained an act of parliament for the purpose. Soon after (33 George 2nd) the Duke of Bridgewater obtained an act for his celebrated canal, and since that period upwards of 2400 miles of artificial canal have been made in England.

Aberdare Canal is a branch of the Cardiff canal; the act was passed 33 George 3. c. 95.; it passes the iron-works of Abernant, Aberdare, and Herwain, and proceeds to the summit of a precipice near the valley of Neath, where an inclined plane unites with the Neath canal; various railroads now communicate with it.

Aberdeenshire Canal proceeds from Aberdeen to Inverury.

Aire and Calder Navigation was perfected about fifty years before any other act passed for making canals, and it is important in the history of inland navigation; 1699 was the year the royal assent was given to the first act of parliament. The river Aire rises in Malham Tarn, a few miles from Settle, in the district of Craven, in Yorkshire; it passes nearly a mile underground, and afterwards issues from the base of a lofty rock; it then bends its course through Airedale to Leeds: at Castleford it unites with the Calder, and the two rivers retaining the same appellation join the Ouse, a short distance from Howden. The Aire is navigable at Leeds, and the distance to its junction with the Calder is about 11 miles, in which distance there is a fall of 43 feet 6 inches, made with 6 locks; from the junction of the two rivers to Weeland the distance is 18¼ miles; here there is a fall of 34 feet 6 inches, and 4 locks.

The Calder has its rise near Todmorden, and becomes navigable at Wakefield; its course thence to Castleford is about 12½ miles, with a fall of 28 feet 3 inches, made by four locks. The total length of the navigation from Wakefield to Weeland is 31½ miles, with a fall of nearly 63 feet; numerous railroads communicate with it. The canal from Haddlesey to Selby was opened in 1788; its length is 5 miles, and the only lock is into the tide-way of the river Ouse. From Leeds to Selby the distance is 30½ miles, on which there are ten locks; from Wakefield to Selby is 31½ miles, with eight locks. The old locks, which have been generally removed, were about 60 feet in length, and 15 feet in width; those now in use are increased 3 feet in width, so that vessels of 100 tons navigate these rivers and canals.

Another canal, uniting Knottingley to Goole, was opened in the year 1826, after surveys and designs made by Mr. Rennie. The length of this canal from Ferrybridge to Goole is 18½ miles, and the fall to low water mark at the latter place 28 feet 9 inches; its width at the surface is 60 feet, and at the bottom 40 feet; the depth is 7 feet. The locks are in length 70 feet, and in width 19 feet, and vessels of 100 tons can now proceed to the towns of Leeds and Wakefield in 8 hours, and from Castleford to Goole there are steam-packets for passengers.

Alford Canal, in Lincolnshire, runs into the German Ocean at Anderby, where it has a sea lock, which maintains the water 14 feet 8 inches above the low water of spring tides,

being equal to high water-mark neap tides. The spring tides averaging about 18 feet 6 inches; there is a rise of 7 feet 9 inches by one lock, and the canal is then a dead level.

Ancholme River Navigation begins at Ferraby Sluice, on the Humber, and terminates at Bishop Briggs; the works were much improved in 1801, under the superintendence of Mr. Rennie. The canal from Caistor falls into the line about 5¼ miles above Bishop Briggs.

Andover Canal commences near that town, and enters the tide-way of Southampton Water at Redbridge.

Arun River Navigation. — The river Arun rises at a place called Haslemere, at an elevation of 920 feet above the level of the sea at low water; the navigation commences at Billinghurst, and is suited for vessels drawing 3 feet water.

Ashby-de-la-Zouch Canal commences near Nuneaton, in Warwickshire, and terminates in the parish from whence it takes its name; it is level throughout, the whole line was completed in 1805. Various railroads are made to communicate with it.

Ashton-under-Lyne Canal commences near Manchester, and proceeds to Clayton, thence to Fairfield, a distance of 3¾ miles, with a rise of 162 feet 6 inches, by eighteen locks. From Fairfield for a distance of 2½ miles it is perfectly level. At the aqueduct of Duckenfield is a branch to the Huddersfield canal, and another 2½ miles in length to Waterhouses, which crosses the river Medlock by an aqueduct, having previously gone through a considerable length of tunnel. The branch from the aqueduct to Holinwood is 1¾ miles in length, and by means of eight locks rises 83 feet. A collateral branch proceeds from the Hollenwood branch, about a mile in length, to Fairbottom Colliery. Several short canals unite with these.

From this canal Manchester derives considerable advantage; it unites that town with Ashton-under-Lyne; by means of Huddersfield canal and other branches, it connects the German Ocean with the Irish Sea, and by the Rochdale canal it unites with the Mersey.

Avon River rises near Devizes, and falls into the sea at the Bay of Christchurch; it is navigable to Salisbury; in the year 1771, the works were much injured by a flood, and were repaired by Mr. Brindley.

Avon River rises near Warwick, and becomes navigable at Stratford-upon-Avon, from whence it flows 43 miles 3 furlongs to Tewkesbury, and then into the river Severn, benefiting in its course the towns of Stratford, Evesham, and Pershore.

Avon and Frome Rivers. — The Avon from the Hanham Mills to the Severn, at King's Road, is navigable for a distance of 15½ miles; a part of its course was through the middle of the city of Bristol, and this has been converted into a floating dock and harbour, by cutting a new channel for the navigation 2 miles in length.

The Frome river rises near Wickwar, in Gloucestershire, and falls into the floating dock at Bristol.

The Avon is subject to high and rapid tides, occasionally rising as much as 50 feet. Smeaton proposed great improvements in the harbour of Bristol, but they were not carried into effect until after the passing of the act of the 48 George 3., when William Jessop was appointed engineer. A part of the Avon has been rendered navigable to Bath; the distance from Hanham Mills to that city being 11 miles, with a fall of 30 feet, by six locks.

Barnsley Canal commences from the river Calder ¾ of a mile below the bridge at Wakefield; it rises in the distance of 2¾ miles a height of 117 feet by means of fifteen locks. There is a reservoir 40 feet in depth, and in area 127 acres, to supply this canal; near Burton it crosses the Dearne by an aqueduct of five arches of stone, 30 feet span each; at a distance of 10 miles from its commencement, it unites with the Dearne and Dove canal. From Barugh Mill to Barnby Basin, where the canal terminates, there is a rise of 40 feet by five locks; its engineer was Mr. William Jessop.

Basingstoke Canal has its commencement on the river Way, 3 miles from where it unites with the Thames: at Ash it enters the county of Southampton; in this distance of 15 miles it rises 195 feet by means of twenty-nine locks. Throughout this length the canal is 36 feet wide, and 4½ feet deep, the locks admitting vessels 72 feet long and 13 feet wide, which carry 50 tons.

By means of an aqueduct about a mile from Winchester, the canal crosses a valley ¾ of a mile in width. At Grewell Hill it passes by a tunnel through the chalk for more than ½ mile, and terminates at Basingstoke; the last 22 miles its width is 38 feet, and its depth 5 feet 6 inches. At Aldershot is a reservoir, which with the river Lodden supplies a part of the canal.

Baybridge Canal commences at West Grinstead, and terminates at the place from whence it takes its name, in the county of Sussex.

Beverley Beck commences from the river Hull, and extends to Beverley.

Birmingham Canal was originally planned and executed by James Brindley; the first act was obtained in the year 1766, and under it the canal was completed, which commences in the river Trent, at Wilden Ferry in Derbyshire, passes through the Potteries, and through Cheshire to the river Mersey at Runcorn. In the same year another act was passed, to branch off a canal from Heywood near Stafford, and proceed by Wolverhampton to the

river Severn at Stourport, near the town of Bewdley. A communication was then made with the ports of Bristol, Hull, and Liverpool, and the Severn, the Humber, and the Mersey. In 1768, another act authorised a canal to be made from Birmingham, through the mining district of Oldbury and Bilstone, to the Staffordshire and Worcestershire canal, 3 miles east of Wolverhampton, a total distance of 22 miles.

The act for the communication with Hull was passed in 1783, when the Fazeley canal, 20 miles in length, was made. The Coventry, Oxford, and Grand Junction canals, afterwards united London to these ports.

	Feet.	Inches.	
The Birmingham summit is - -	464	5	above low water at Liverpool.
The Staffordshire and Worcestershire -	352	3	Ditto.
At the Fazeley Junction - - -	219	0	Ditto.

In the year 1824, Mr. Telford was applied to on the subject of improving these canals, then deemed inadequate to the growing industry of the district; he found them little better than crooked ditches, and with scarcely the appearance of a towing path. Aided by the celebrated James Watt, he succeeded in cutting off the numerous bends in the canals, and making one nearly straight from Birmingham to the summit at Smethwick, where a new cut was made 70 feet in depth, and the length of the main line from Birmingham to Autherley reduced from 22 to 14 miles. The canal was enlarged to 40 feet in width, with perpendicular banks and walled sides, and the bridges to 52 feet in breadth between the abutments, so that the hauling-paths were continued without contracting the water-way of the canal.

Embankment at Rotten Park forms a reservoir of 80 acres, with a depth of 45 feet at the head of the retaining bank, the bottom of which is above the Birmingham summit, so that all the water it contains is rendered serviceable. The feeders of this great supply are from the old reservoirs at Oldbury and its neighbourhood.

Mr. Telford also removed the six locks, three ascending, and three descending, which were on the line between Birmingham and the Collieries; to effect this 1,697,000 cubic yards of earth were excavated in the distance of 2 miles; the slopes of the banks are $1\frac{1}{2}$ horizontal to 1 perpendicular.

The greatest depth of cutting is 71 feet; the water-way of the canal is 40 feet in width, and 5 feet 6 inches in depth. The whole is walled with stone, there is a towing-path on each side 12 feet in width. Over this cutting are numerous brick and stone bridges, the construction of which show great ingenuity; several are built askew. At the point where the cutting is deepest is an iron bridge, 150 feet span, over which is the public roadway, 26 feet in width; the other two bridges are only 52 feet span.

An aqueduct of two arches near Spon Lane carries the canal across the new works; and at Smethwick is an elegant iron aqueduct, through which the surplus water is conveyed, from the upper level of the old canal across the new works into a feeder, which carries the water to the reservoir before mentioned.

At Smethwick the upper level descends into the improved new line of canal, and between this place and the town of Birmingham, a distance of $4\frac{3}{8}$ miles, nearly 2 miles have been saved; the quantity of earth removed to complete the three embankments and the intervening deep cutting was 370,000 yards. Here the canal is also walled on each side, has a double towing path, and is 40 feet in width at the surface of the water: there are several brick skew bridges, some upwards of 50 feet span; at Bloomfield is an excavation, extending towards Deepfield, where the cutting is 90 feet in depth, and the canal 24 feet in width, and 5 in depth; the sides are walled, and the towing path is continued on each side. To effect this more than 1,000,000 yards of rock and earth were removed.

Birmingham Canals. — The old Birmingham commences near that town, and at Smethwick there are three locks, rising in all 19 feet 9 inches; at Autherley it locks down by means of 21 locks, 132 feet.

Birmingham and Fazeley Canal commences near Farmer's Bridge in Birmingham, and passes by part of the Coventry Canal to near Tamworth; this distance of 15 miles has a fall of 248 feet; the canal afterwards forms a part of the old Coventry, and continues another $5\frac{1}{2}$ miles to Whittington Brook, where it communicates with the Wyrley and Essington canal. It is united to the Warwick and Birmingham by the Digbeth branch, which is in length 1 mile 2 furlongs, and has a fall of 40 feet by six locks; there is a short tunnel at Curdwath, and at Salford bridge an aqueduct of seven arches of 18 feet span each. By these canals a communication was effected between London and Hull.

Birmingham and Liverpool Junction Canal was commenced under an act passed in the year 1806. The whole length is 39 miles, besides the Newport branch of 9; its width at the surface is 36 feet, at the bottom 16, and its depth 5 feet.

This canal leaves the Staffordshire and Worcestershire canal about 3 miles from Wolverhampton; nearly opposite to Autherley, it passes on a level for 3 miles with one lock; thence on to Market Drayton, a distance of 15 miles, where is the second level; near the last mentioned town are five more locks, and 5 miles beyond there, at Adderly, five others.

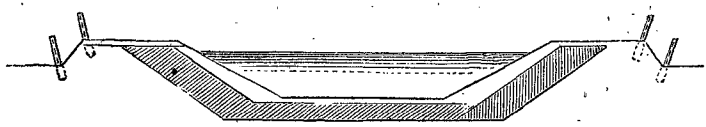


Fig. 539. SECTION OF CANAL WHERE PUDDLED.

At Audlem in Cheshire are fifteen locks in one chain; 12 miles north of the river Weaver are two more, making twenty-eight locks in all upon the main line, besides those on the

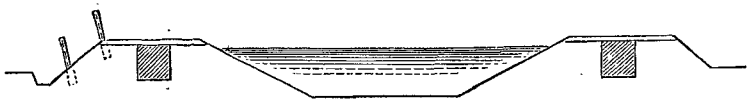


Fig. 540. SECTION OF CANAL.

Newport branch. These locks are 82 feet in length, and 7 feet 6 inches in width, and admit a boat 7 feet wide, carrying 24 tons.

At Nantwich is a cast-iron aqueduct, the arches of which span 30 feet and rise 4 feet.

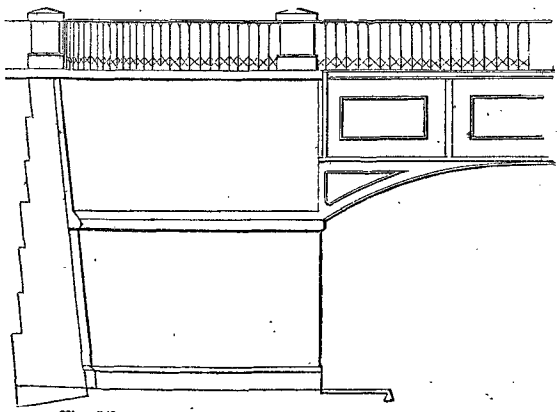


Fig. 541. AQUEDUCT.

Thirteen miles from the south end of the main line, in the township of Norbury, the Newport branch commences, which falls into the Shrewsbury canal, in the township of Wappenhall. This canal is 11 miles in length, and has a fall of 139 feet, by similar locks to those of the main line: its supply of water is thus obtained; its summit being upon a level with the Staffordshire canal, and under that of the Birmingham canal, communicating with the latter at Autherley, every boat passing to or

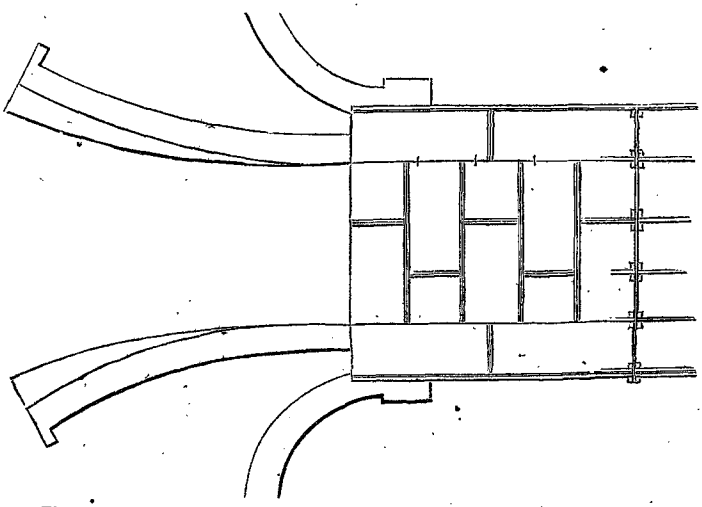


Fig. 542. PLAN OF AQUEDUCT.

from the Staffordshire into the Birmingham and Liverpool Junction, brings with it a lock-full of water, and as this is received into the summit level, it serves throughout the whole

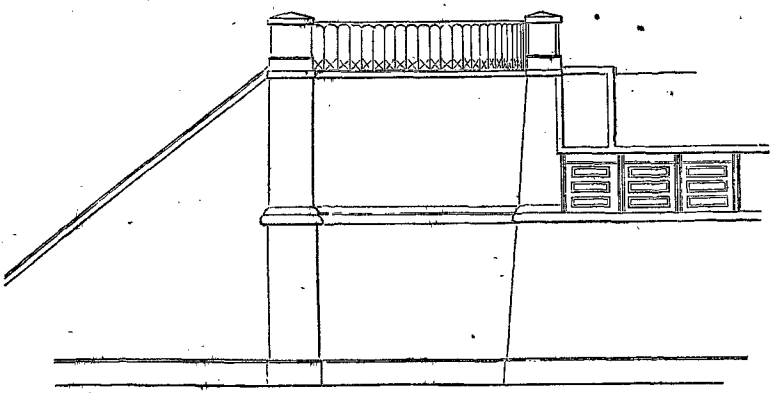


Fig 543. SIDE OF AQUEDUCT.

passage to the Mersey. To provide for evaporation, there is a reservoir of fifty acres at Belvide, and another of the same size at Knighton; these two reservoirs are shallow, but they will allow a foot in depth to be drawn off, if required for lockage water.

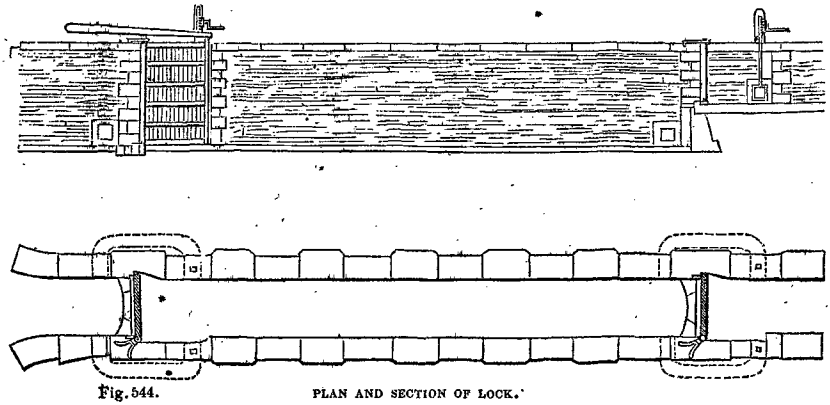


Fig. 544. PLAN AND SECTION OF LOCK.

The Cheshire marl used for the embankments stood very well where the height did not exceed 10 or 12 feet, but was found hazardous beyond that, not retaining its shape, and slips and bulges occurring to a great extent.

Blyth River rises near Laxfield, and terminates at Southwold in Suffolk.

Borrowstounness Canal proceeds along the south side of the Firth of Forth, and unites with the Forth and Clyde canal near the mouth of the Carron rivers.

Bradford Canal commences near Shipley, and terminates at Hoppy Bridge.

Brecknock and Abergavenny Canal commences near Pontypool; it crosses the Avon by an aqueduct, and then, by a tunnel 220 yards in length, it proceeds to Abergavenny and Brecon.

Bridgewater Canal (the Duke's) extends from Worsley to Manchester. From Castlefield it proceeds to Longford Bridge, a distance of 3¼ miles; 18¾ miles further it joins the Trent and Mersey, and at 5¼ miles arrives at Runcorn; it then falls into the Mersey by ten locks, which are together 82 feet 6 inches.

The Worsley branch is 5 miles; and from thence to Leigh 6 miles. This canal, executed at the expense of the Duke of Bridgewater, who has been justly called the father of British inland navigation, is on one level the greatest part of its length: this is done by means of lofty and wide embankments; one of these, over Stretford meadows, is at the base 112 feet wide, and 17 feet high; the Barton aqueduct, which is 39 feet above the Mersey and Irwell navigation, is 200 yards in length.

Excepting for a distance of 600 yards at Runcorn, where the rise is 82 feet, the rest of the navigation for 73 miles is on one level, which is effected by means of tunnels, aqueducts and embankments of considerable magnitude, and as all this was performed in the infancy of canal operations, it reflects the highest honour on the projector and his engineer.

Bridgewater and Taunton Canal commences on the Avon, 6 miles below Bristol, and terminates near the town of Taunton.

Britton Canal commences 3 miles below the town of Neath, and terminates at the pool called Swansea Harbour.

Bude Harbour and Canal: this canal commences at the Port of Padstow, and after passing through a considerable length of tunnel, terminates at Thornbury; there are several branches, as the Launceston, Moreton Hall, Verworthy, Druxton Bridge, &c.

Bure or *North River* becomes navigable at Coleshill, in Norfolk, and continues so to Aylsham.

Bure, Yare, and *Waveney Rivers,* and *Yarmouth Haven.* The navigation of the Bure commences at Coleshill, and continues for 13¼ miles to a place where it unites with the Yare. The Ant river branch commences at Wayford Bridge, and after an 8 miles course enters the Bure. The Thurne River branch begins at Huckling Broad, and running 7 miles, falls into the Bure at Thurne. Eight miles from Yarmouth, there is a cut from the township of Tunstal 1 mile in length.

The Yare becomes navigable at Norwich, and after receiving the Bure at Yarmouth, falls into the roads of that place, a distance of about 32 miles. The Waveney is navigable at Bungay, and falls into the Yare at Burgh Flatt, after a course of 25¼ miles.

Bury, Loughor, and *Lledi Rivers.*—The Bury is a wide estuary, terminating at Worm's Head, on the southern coast of Caermarthenshire, its course is about 12 miles. The Loughor, from the ford to the estuary of the Bury, is 2 miles. The Lliedi falls into the Bury near Llanelly.

Caistor Canal commences near Creampoke, and terminates 3½ miles west of the town of Caistor in the county of Lincoln.

Calder and Hebbel navigation commences about 2 miles from Halifax, at Sowerby Wharf, and terminates a little below the bridge at Wakefield, at Fall Ing, where it unites with the Aire and Calder navigation.

Caledonian Canal.—The Highlands of Scotland are divided by a series of lakes, called Lochs Ness, Oich, Lochi, Eil, and Lynnhe, which run in a direction from north-east to south-west, and from their contiguity afforded a favourable opportunity of uniting the seas of the eastern and western coast. Twenty-one miles only of canal was requisite to obtain a navigable line for the entire extent, upwards of 100 miles.

In 1802, a survey of the coasts and the interior of the country was made by Mr. Telford, by order of the Lords of the Treasury, for the purpose of forming the canal from Inverness to Fort William. After Mr. Jessop's and Mr. Rennie's opinion had been taken on the possibility of effecting this desirable line of communication, an act was passed directing the works, and regulating the expenditure; Mr. Telford was appointed engineer.

The length of the excavations for the canal is 21½ miles; that of the intermediate lakes 37¼ miles, making a total of 58¾ miles.

The breadth of the canal at the top is 122, at the bottom 50, and the depth 20 feet. From each side of the flat bottom the sloping sides are in height to the breadth as two to three. The slopes are continued to within 2 feet of the level of the water, where the bank is 6 feet wide. There are twenty-three locks, 40 feet wide, and 172 feet in length. The entrance is 10 miles from Fort George, and 1 mile to the north-west of the river Ness, where the tide-way of Beauley Water is from 5 to 7 fathoms in depth.

The tide-lock is 400 yards from high-water mark, at the end of an embankment; its chamber is in length 170 feet, in width 40, and the rise 8 feet. The canal is afterwards formed upon a flat and muddy shore, by artificial banks, until it reaches high-water mark at Clachnacharry, where a similar lock is constructed on a foundation of hard clay. South of this is a large floating dock, 967 yards in length, and 162 in breadth, the area being computed at 32 English acres.

At the south end of the basin are the four united Muirtown locks, each in length 180 feet, in breadth 40, together rising 32 feet, and bringing the waters of the canal to the level of those of Loch Ness. The canal here measures 120 feet at the surface, 50 feet at the bottom, and in depth 20; and by an easy bend winds to Torvaine on the Ness river.

Before the canal enters the Loch of Doughfour, 6 miles from its starting point at Clachnacharry, it passes a regulating lock, 170 feet in length, and 40 feet in width, and then unites with Loch Ness, at a small outlet, at Bona Ferry. Loch Ness is nowhere less than a mile in breadth; its depth varies from 5 to 129 fathoms; its whole length is about 22 miles.

Fort Augustus is situated at the south-west end of Loch Ness, and on its north side the canal ascends by five connected locks a height of 40 feet, each lock being 180 feet in

length; it then proceeds to the north-east corner of Loch Oich, after having passed the lifting lock at Kytra, which is 170 feet in length, and 40 feet in breadth.

Between the western end of Loch Oich, and the east end of Loch Lochy, forty feet depth of cutting was required, and near the latter place is a regulating as well as a lifting lock; the difference between the surface of the water in these two locks is nearly ten feet.

At the south-west end of Loch Lochy is another regulating lock; the whole length of the Loch is not less than 10 miles, and its ordinary level is continued along the canal to within 1 mile of Loch Eil, where there are eight connected locks, each 180 feet in length, and 40 feet in width, falling altogether 64 feet; this work forms a mass of masonry 1500 feet in length; each of the locks rises 8 feet.

The canal continues on a level, until it arrives at the two connected locks at Corpach, which fall 15 feet, where there is a single sea-lock, which enters the tide-way of Loch Eil. This is situated at the western extremity of the canal, within 300 feet of high-water-mark. The rock being covered at three-quarters flood, it was necessary to lay the sill in such a position on the rock that a depth of 21 feet water might be obtained upon it at high-water of neap tides. Water-tight mounds, faced with rubble-stone, were formed for this purpose from the shore, beyond the extremity of the lock-pit, which were connected by a wooden cofferdam. A foundation was arrived at after boring to a depth of 63 feet below the lower water line of spring tides; a sufficient space was enclosed with a cofferdam, which was framed on the eastern bank, and afterwards put together on the beach, near high-water mark.

The leading frame was made by fixing together, end to end, two pieces of timber, crossed by others 20 feet long, 13 inches broad, and 6 inches thick, laid on opposite sides of the first beams, across the joinings, and fastened by four screw bolts, which passed through the whole. When these beams were so fished together, their whole length was 95 feet.

To unite the two sides, two others, each 63 feet in length, were laid with mutual inclination, the ends being 63 feet apart; these were secured to the two long beams at the ends by halving, or corking down; after which two iron screw bolts were passed through each. Another beam, 38 feet in length, was laid across each angle, and also screwed to the other beams at the two ends.

When the spring tide was at its height, the first leading beam was floated off, and at low water was sunk into its proper situation by attaching several large stones to it at its upper side, three mortises were cut on each side and three in the front, to receive the standards, which were to be tenoned into them, and which, after being placed upright, were cut off to the level of one foot below high-water neap tides, that they might receive the middle leading frame, which was made on shore, floated to its place, and sunk by means of guide piles, driven by a pile engine, placed upon the deck of a sloop, and then secured by screws to the tops of the upright standards already mentioned.

On the top of this second frame upright standards were placed in mortises, which were cut off at high-water spring tide. The upper leading frame was then floated off, and placed upon the last-mentioned standards, and also bolted to the piles. On this was formed a temporary scaffold, by laying large timbers across, and driving piles within the space to support them; when this was done, the whole was loaded with large stones, and a pile engine; fixed piles were driven at from 15 to 20 feet apart, entirely around the whole, and these were so securely bolted to the upper frame, that the storms had no effect upon them.

In March, 1808, the main framing piles were fixed to the rock by iron dowells, and this was performed by means of a cylinder, 8 feet long, and 22 inches internal diameter, formed of 3-inch plank. The joints were closely united and dowelled together, and the whole hooped with iron, and shod at the lower end with a circular iron shoe. On its upper end were two strong iron eyes, fixed by means of clamps, which were riveted to the sides of the cylinder, and through them passed the iron chain which lifted it up.

At low water the cylinder was placed where the main pile was to lie, there being then only 3 feet of water, and 8½ of silt and gravel on the rock; it was then placed upright, close to the inside of the lower leading frame, and on its top was a block of ash timber, 2 feet in height, on the under side of which a piecer turned, 6 inches in length, fitting exactly to the top of the cylinder; this prevented the block from shifting, as well as the crushing of the cylinder whilst being driven. This block and the pile 12 inches square, placed on the top of it, were hooped with iron: the pile was as much above the top of the upper scaffold as it was necessary to sink the cylinder in the mud. When all was perpendicularly placed, a pile-engine, 30 feet in height, was applied to drive it, with a ram of 1008 pounds weight. When the cylinder had descended some depth into the mud, it was found necessary to empty the contents; this was effected by an auger, which filled at two complete turns, when it was lifted out by a purchase at the top of the pile-engine, and the sand cleaned out by means of a shovel.

When the cylinder had reached the rock, a frame, which fitted it, was introduced into the upper end, and sunk by means of two half hundred weights, and in the middle of the frame, through a hole 4 inches square, was passed a funnel which tapered to 3 inches at the bottom; this was driven down to the rock, and the sand enclosed in the funnel was cleared out, by a cylindrical iron tube, 3 inches diameter, and 3 feet in length, which had a valve fixed within 2 inches of the bottom, resting on a small ring, fastened to the inside of the tube, on the top of which was a screw, by which it was attached to a set of boring-rods.

It was then passed down to the bottom of the square wooden pipe, and working by short and quick strokes, the sand and gravel were brought by the agitation of the water above the valve; the tube was then drawn out and emptied; this was continued until the whole surface of the rock within the square tube was perfectly clean.

Through the square directing pipe a jumper was then passed, worked by a lever on the upper scaffold, until a hole 20 inches in depth, and 2½ in diameter, was bored into the rock, into which an iron dowel, 2 inches square, might be placed; this was effected by fastening it to a square socket, made in the end of 1½-inch square iron bar, a small cord being attached to it, to prevent its falling out of the socket whilst lowering the square directing pipe to the rock: when it had arrived there, it was driven into the hole in the rock by striking the head of the bar several times with a hammer. After it was driven 18 inches into the hole, the timber was lifted up by a sudden jerk, which broke the cord, and left the dowell in its place, the frame and square directing pipe being also lifted out of the cylinder. The pile to be let down had two hoops round its lower end, and a hole cut to receive the end of the iron dowell already placed upright in the rock.

On the lower end of this pile were nailed four other pieces, so as to increase its size to 22 inches, the diameter of the cylinder, by which means it could be securely placed exactly over the iron dowell by a stroke of the pile-engine.

To the chain fixed at the top of the cylinder a lever was applied, 50 feet in length, the fulcrum of which was laid on the top of the main piles, and the other end lifted by ropes and blocks from the mast of a sloop. It required a purchase of 50 tons to start the cylinder; it was lifted up over the tops of the piles by the aid of ropes and blocks. The head of the pile so fixed was then forced against the inner side of the leading frame, and a screw bolt put through both. The apparatus was then shifted to the others, until the whole of the main piles were fixed. Temporary leading beams were then fastened to the heads of the first piles, at 15 or 20 feet apart, round the outside of the main leading frames, and these spaces filled up by driving other piles, side by side, down to the rock. The lower temporary leading frame was then taken off, the inside braces put in, which rested on brackets fastened to the main piles.

The outer row of piles was placed in front of the cofferdam, by means of a float made of pieces of fir timber 1 foot square, and 40 or 50 feet in length, fastened together by spiking others across them. This float, 14 feet in length, filled the space between the rows of piles, and was not only kept steady by them, but served to regulate and maintain their parallel distance.

When the outer row was driven, a leading beam made by fishing was bolted to the outside of the piles, on a level with the inside leading frame; a temporary leading frame was then fixed on the inside of the outer row of piles, 1 foot lower than the outside beam; a scaffold was erected on the top, and an outside leading beam bolted, at the same level with the leading frame on the inside.

The space between the first-mentioned piles was now filled up by others set close together, and driven down to the rock. The bank and puddles on each side of the dam being by this time brought forward as far as the inner row of piles, the connecting bolts were placed through each pile opposite the middle of the leading frame, through which it passed, across the puddle, and through the front leading beam on the outside of the outer row of piles. Each of these connecting bolts was fastened by a strong cotterel through each end, with a strong iron plate under them; two of these bolts passed through each of the main piles in front of the dam, one through each of the leading frames and the other 1 foot below low water of ordinary spring tides, at which level the leading beams on the outer row of piles was fixed. The two rows of piles were maintained in their position by pieces of timber being joined on each side of the main pile on the inside of the dam, and spiked down on the outside of the leading beams. When the banks and cofferdam were finished, and the engine commanded the water, the works were proceeded with in the usual way, and after enough of the rock had been removed the masonry was commenced. The locks on this canal are of unusually large dimensions; the whole work, forming a junction between the two seas, was opened at the end of the year 1823.

Artificial embankments have already been described, as made for the canal, 400 yards in length beyond high water-mark on the shore of Loch Beauley at Clachnacharry, where the foundations were of mud so soft that an iron rod could be thrust down 55 feet with ease.

In this situation it was not deemed practicable to form a wooden cofferdam sufficiently large to construct a lock 170 feet in length, and 40 feet in width, besides the necessary wing-walls, and the following method was therefore adopted. An iron railway was laid down, on which the heavy mountain clay found close by was carted, and the two banks of the canal were first formed as far as where the depth of water at an ordinary neap tide was 20 feet; and when the site of the intended lock was approached, the banks were united into one mass; the mountain clay compressed the soft mud beneath and squeezed out the water. Upon this great mound of earth a quantity of stone was laid, which was afterwards used in the construction, and remained for six months, at which period the mound had sunk 11 feet, and it being considered that no further material sinking would take place, a lock pit was excavated in the solid mound, and the water was kept down by a steam-engine of nine horse power. When the lock pit was excavated, rubble stone masonry was laid with hydraulic mortar to the thickness of 2 feet in the middle of the lock chamber, increasing to 5 feet thick on each side; upon this an inverted arch of square masonry was struck, and on it was built the side walls; the chamber walls, counterforts, recesses, and wing-walls were then carried up.

The masonry of the bottom part was built in lengths of 18 feet, in order that the mud might be prevented from again rising up in the space newly compressed. The mud was easily penetrated by piles, but after they had been driven a few hours, no power could either drive them further or draw them out. The whole of the masonry was completed in 1812, the rise of the lock being 6 feet 8 inches. The system adopted was found to have been far less expensive than a cofferdam.

The five connected locks at Fort Augustus have their foundation on a coarse open gravel, and to construct them it was found necessary to turn the river Oich. A trial pit was then sunk by means of a steam-engine of six-horse power; but when a depth of 18 feet was obtained, the water accumulated so fast, that a pump well and an engine of 36 horse-power were required, which enabled the lock bottom wings and forebay walls to be constructed, though during the progress of these works, a third engine of nine horse-power was used, and when the depth arrived at was 25 feet below the surface of Loch Ness, the whole three engines were required to keep the waters down.

There is a let-off or outfall between Corpach and Loch Lochy, at Strone, which consists of three sluices, each 4 feet broad and 3 feet high, the sills being on a level with the bottom of the canal, and the inside faces of the water surface ranging with the bank line; the water falls 9 feet before it reaches the rock on which it falls; the frames and sluice doors are of cast-iron, the working parts being faced with copper; the sluice doors are raised and lowered by rack-work, enclosed in cast-iron cylinders, placed over the centre of each, and rising 1 foot above the surface of the canal when full.

The length of the canal operated upon by this let-off is 6 miles, where it is 80 feet wide at the surface, 50 feet at the bottom, and 10 feet deep, and the three sluices when opened lower the water as follows: —

			hr.	min.
From 10 feet	to the depth of	9 feet	1	39
9		8	1	42
8		7	1	45
7		6	1	49
6		5	2	6
5		4	2	38

The freshwater lakes form 37½ miles of its length, and vessels are admitted drawing 15 feet water.

The total expenditure from its commencement in 1803 to May, 1829, was —

	£
For work performed by contract and measurement	652,494
Ditto, by day work	68,099
Expenses of management for timber, machinery, shipping, land purchased, &c.	261,766
	£982,359

The price of Baltic timber at its commencement was 2*s.* 6*d.*, and got up to 7*s.* per foot cube. The lock gates are of English oak and cast-iron; there are fourteen locks on the west side, and thirteen on the east side of the summit. The turn-bridges are all cast-iron.

Carlisle Canal, 11½ miles in length, was executed under the direction of William Chapman, a native of Whitby, at a cost of about 120,000*l.* It commences on the south-eastern side of Carlisle, and falls into the sea through a height of 70 feet, by means of 9 locks. At Carlisle there is a basin of considerable extent, and the first reach is 4 miles in length: it then falls 46 feet by 6 locks, in the length of the next 1¼ miles: it is then nearly level to Bowness, and afterwards falls into the sea by three locks, the lift of each being 8 feet; between these are two basins, called the Upper and Lower Solway; the latter is on a level

with high water of the lowest neaps, and the other is 15 feet 6 inches higher. The depth of water in the canal is 8 feet; the locks are 17 feet wide and 74 feet long, and the supply is drawn from a reservoir, into which the waters of the Eden are pumped up.

Mr. Chapman showed considerable ability as an engineer in the execution of this work, and was very extensively employed till his death, which took place 29th May, 1832, in his 83d year.

Chesterfield Canal commences at Stockwith in Nottinghamshire, and terminates at Chesterfield. From the Trent to Worksop, a distance of 24 miles, it rises 250 feet, and in the next 9 miles it rises 85 feet. Between the summit and Chesterfield, a distance of 13 miles, the fall is 45 feet; between Wales and Harthill is a tunnel 2850 yards in length, 12 feet high, and 9 feet 3 inches wide.

Coventry Canal commences on Fradley Heath, and ends at Coventry; it is joined in its course by the Wyrley and Essington Canal, and by the Birmingham and Fazely. The first 11 miles is level; near Tamworth there is a rise of 14 feet 6 inches by two locks; from thence to Grendon, 6½ miles, it is level; from the latter place to Atherstone, a distance of 2½ miles, there is a rise of 81 feet 6 inches; it is afterwards level to Coventry.

Crinan Canal crosses an isthmus in Argyleshire, commencing at Ardreshaig in Loch Gelph, and falls into Loch Crinan near Duntroon Castle.

Cromford Canal, the engineer to which was Mr. William Jessop, commences near Langley Bridge, in the county of Northampton. The top width of the canal is 26 feet, and the boats employed upon it are 80 feet in length, 7 feet 2 inches wide, and 3 feet 4 inches deep; when loaded with 22 tons, they draw 2½ feet of water, and when empty about 9 inches. The tunnel at Ripley is 9 feet wide at the surface of the water, and from thence to the crown of the arch it is 8 feet high: for the construction of this tunnel, which is 2966 yards in length, thirty-three shafts were sunk, some of which were 210 feet in depth; the cost of this work averaged 7*l.* for each yard in length. There is an aqueduct bridge near Wigwell over the Derwent, 200 yards long, and 30 feet high, the arch over the river having a span of 80 feet; near Fritchly is another aqueduct, 200 yards long and 50 feet high, and the two cost 6000*l.* The reservoir of 50 acres over the Ripley tunnel is 12 feet in depth, and contains 2800 locksfull of water, which is discharged by a large pipe and cock in one of the tunnel pits; the embankment of this reservoir is 200 yards long, 156 feet wide at the base, and 12 feet wide at the top: there are two other reservoirs, one containing 20 and the other 15 acres. The engineer has informed us that for cutting and wheeling the clay, the price usually paid for a stage of 20 yards was 3½*d.* per cube yard, for gravel 4½*d.*, and that the entire cost of the canal was 80,000*l.*; it was completed in 1793.

Dearne and Dove Canal commences near Swinton, and near Dunn passes through a short tunnel, and terminates near Barnsley.

Derby Canal commences on the Trent, near Swarkstone, and terminates at Little Eaton; there is a branch to Erewash Canal.

Dorset and Somerset Canal commences at Gains Cross, and terminates in the Kennet and Avon Canal at Wedbrook.

Droitwich Canal commences in the town of that name, and terminates at Hawford Bridge, where the Salwarp river falls into the Severn; this work is said to have been by Brindley, and is most admirably executed.

Dudley Canal proceeds from the Worcester and Birmingham Canal, at a place near Selby Oak, and near Stonehouse enters the Lapal tunnel, which is 3776 yards long; beyond Hales Owen is another tunnel 623 yards long, and at Dudley Woodside a third 2926 yards in length, a short distance beyond which the canal communicates with the Birmingham. There is a branch canal two miles in length, called the Black Delph, which falls into the Stourbridge Canal.

Edinburgh and Glasgow Union Canal has its commencement two miles west of Falkirk, at the sixteenth lock of Forth and Clyde navigation. Over the Avon is an aqueduct 80 feet above the surface of the river; this canal terminates by a basin at the Lothian road; it is fed at one place by a suspension aqueduct, which crosses the Almond river.

Ellesmere and Chester Canal leaves the tideway of the Mersey at Ellesmere Port, crosses the river Ceiriog by a stone aqueduct, and at Pont Cysyllte by an iron one, and falls into the Montgomeryshire Canal.

The Llanymynech branch leaves at Francton common, out of which is another, which terminates at Weston Lullingfield. The main line of the canal rises 46 feet in the first 8¾ miles; from Chester to the Harleston locks is 15¾ miles, with a rise of 131 feet, by means of eleven locks. From these locks to Francton Common it rises 115 feet in a distance of 25 miles; from Francton Common to its termination in the Montgomeryshire Canal, it is 11¼ miles, with a fall of 52 feet. The branch from Wardle Green to Middlewich is in length 10 miles, with a fall of 44 feet 4 inches by four locks; that to Ruabon Brook Railway is 11 miles in length, with a rise of 13 feet. The aqueduct over the Dee, at Pont Cysyllte, has a height of 125 feet; the pillars are 52 feet apart. The trough through which the vessels pass is 320 feet long, 20 feet wide, and 6 feet deep, formed entirely of cast-

iron plates. The original plans for this undertaking were made by Mr. William Jessop. This canal unites the Severn, Dee, and Mersey, and consists of a series of navigations, commencing from the river Dee, in the Vale of Llangollen, passing near Ellesmere, Whitchurch, Nantwich, and Chester, to Ellesmere Port, on the Mersey, in one direction; through the middle of Shropshire, towards Shrewsbury, on the Severn, in another; and in a third, by the town of Oswestry to the Montgomeryshire Canal at Llanymynech; the whole length, including the Chester Canal, being 103 miles. An act of parliament was obtained for this work in 1793. Mr. Telford was employed, and it was the occasion of his attention being more particularly called to the study of civil engineering.

Ellesmere Port, on the Cheshire side of the Mersey, is 12 miles from Liverpool; here the canal commences; from thence to Chester is 9 miles, and from Chester to Nantwich 20 miles. For the whole of this distance the locks will admit barges whose beam is 14 feet. The perpendicular rise from low water in the Mersey to Nantwich is 1[illegible] feet.

From Nantwich to Whitchurch is 16 miles, with a rise of 132 feet; from thence to Ellesmere, Chirk, Pont-y-cysyllte, and to the river Dee 1¾ miles; above Llangollen (including the Prees branch) the distance is 38¼ miles, and the rise only 13 feet, in all 322 feet above low water at Liverpool. About 3¾ miles west of Ellesmere, at Francton, the canal descends 30 feet, and from thence passes on a level to Weston Llulling fields in one direction, and in another 10¼ miles to Llanymynech, with a fall of 19 feet, where it joins the Montgomeryshire Canal.

The greater part of the fifty-one locks are only calculated for boats of 7 feet beam. They are of the usual form, but the gates are chiefly of cast-iron. For locks of 14 feet beam, the lower gates, which are in two leaves, have cast heads, heels, and ribs in separate pieces, with flanches, which are fastened together with nuts and screws; the whole is then covered with wooden planking. The price of the lower pair of gates so formed in locks, with a rise of 8 feet 6 inches, was 102*l.*, and for the upper gates, where each valve was cast in a single piece, 59*l.* 10*s.*: at this time iron was computed at 14*l.* per ton delivered. These gates show no symptom of decay, even at the present day.

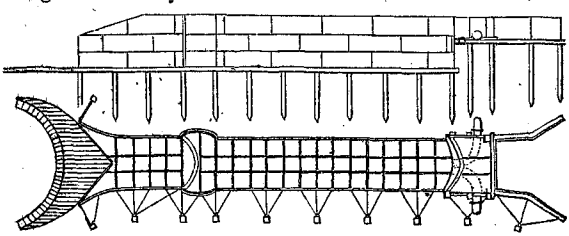


Fig. 545. CAST-IRON LOCK; PLAN AND SECTION.

Cast-iron Locks opposite Beeston Castle, Cheshire. Here are two locks rising 17 feet, built entirely with cast-iron upon a stratum of quicksand: they answered the purpose admirably, and, for this peculiar and difficult foundation, were the best that could be adopted, though the cost in the first instance was considerable.

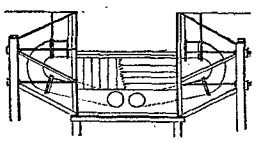


Fig. 546. SECTION OF LOCK.

The aqueduct over the valley of the Ceiriog, between Chirk Castle and the village, is 710 feet in length; the surface of the water in the canal is 70 feet above the level of that

Fig. 547. AQUEDUCT OVER THE CEIRIOG.

of the river below. There are altogether 10 arches, each of 40 feet span; the total breadth at the top is 22 feet, that of the water is 11 feet, and the depth 5 feet.

The piers are 33 feet in depth, and 13 in width, or a little less than a third of the span of the arches which rest on them; these are all constructed in stone, and in the spandrills are longitudinal walls, supporting the cast-iron plates which form the bottom of the canal. These plates have flanges cast on their edges, and are united by means of nuts and screws; on these the sides of the canal, which are 5 feet 6 inches thick, are built with ashlar masonry, backed with hard burnt bricks laid in Parker's cement; the outside was faced with rubble stone-work, like the piers and arches.

Under the towing-path, and beneath the gravel, a thin bed of clay was laid, and the outer edge protected by an iron railing; the iron bottom plate forms a continued tie, and prevents the walls from splitting. This work was completed in 1801, at a cost of 20,898*l.*; the whole, with the exception of quoins, coping and lining the sides of the water-way, which is of ashlar masonry, is of rubble work laid in good lime mortar.

Aqueduct of Pont-y-Cysyllte is 4 miles from Chirk, over the river Dee; an earthen embankment was pushed forward until the perpendicular height became 75 feet. The distance

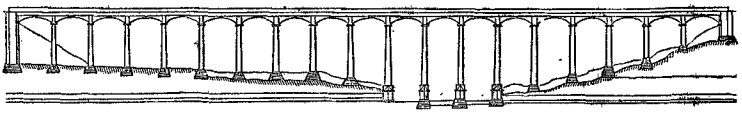


Fig. 548. AQUEDUCT OVER THE DEE AT PONT-Y-CYSYLLTE.

between the end of this and the north bank is 1007 feet, and the river Dee is 127 feet below the water level of the canal carried over it.

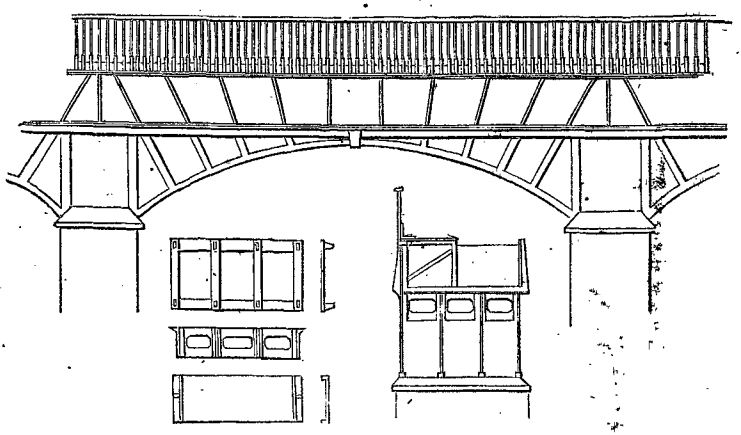


Fig. 549. AQUEDUCT OVER THE DEE AT PONT-Y-CYSYLLTE.

To construct an aqueduct upon the usual principles, with piers and arches, 100 feet in height, and of a sufficient breadth and strength to afford room for a puddled water-way, would have been, not only extremely hazardous, but expensive. Telford, who had already carried the Shrewsbury canal by a cast-iron trough 16 feet above the level of the ground, formed the idea of doing the same in the present instance, and made a model of a portion set on two piers, with the towing path and side rails, which was approved of and finally adopted. The foundation on which the piers are erected is a hard sandstone rock; their height above low water in the river is 121 feet, at the bottom they are 20 feet by 12, and at the top 13 feet by 7 feet 6 inches. For a height of 70 feet from the foundations, they are built solid, and the remaining 50 feet hollow, the walls being only 2 feet in thickness, with one cross inner wall; by this means the centre of gravity is thrown lower in the pier, and the masonry economised.

The width of the water-way is 11 feet 10 inches, of which the towing-path covers 4 feet 8 inches, leaving 7 feet 2 inches for the boat; as the towing-path stands upon iron pillars, the water fluctuates and recedes freely as the boat passes.

There are eighteen of these stone piers, besides those of the abutments, and the total expense, including the embankment, was 47,018*l*.

	£	s.	d.
The embankment cost	8,570	15	8
Masonry	21,162	13	5½
Iron work	17,284	17	5½
	£47,018	6	7

This aqueduct almost rivals the works of a similar kind left us by the Romans. The introduction of iron, however, for the watercourse, is a novelty with which they were unacquainted; in this instance it has proved admirably well fitted for the purpose to which it is applied; had a stone or brick channel been constructed at this great elevation, it could not have been rendered so secure for the passage of boats, as there would have been a constant leakage from the motion and friction of the water within it. The cast-iron plates which form the sides are strongly riveted and secured to those at the bottom, and

wherever possible, ties and braces are introduced: the platform which supports the towing path adds greatly to the strength of the side to which it is attached, and the water passing under it prevents in a great measure any injurious consequences from the swell occasioned by the boats in their transit. The span of the arches is 45 feet, and their rise above the springing 7 feet 6 inches.

Upon this canal are two short tunnels, one 500, the other 200 yards in length, both in the rugged ground which lies between the rivers Dee and Ceiriog; they are each 14 feet 7 inches high, 14 feet wide, and the towing-path covers 4 feet 9 inches, leaving 9 feet 3 inches water-way; this path also stands upon pillars, so that the water is allowed its swell without great interruption.

The general summit of the canal is supplied by a navigable feeder 6 miles in length, carried along the bank of Llangollen valley from the river Dee at Llandisilio; a constant supply of water being ensured by a regulating weir, which dams up the Lake of Bala Pool, 4 miles in length, situated about 20 miles from Llandisilio.

Adjacent to Mantwick, where the Ellesmere canal unites with the Chester, the distance to the Trent and Mersey, or Grand Trunk canal, at Middlewick, is only 11 miles; in 1826, an act was passed to unite them by a canal, and the works were speedily completed. This branch of 11 miles has a fall of 44 feet; the locks are 82 feet in length, and 7 feet 6 inches in width. The canal is 16 feet wide at the bottom, 36 feet at the surface, and 5 feet deep, and obtains its chief supply from the Dee.

Erewash Canal, proceeds from the Trent, near the village of Sawley, and terminates at Langley bridge, by uniting with the Cromford canal. From the Trent to where the Derby branch locks down is $3\frac{1}{4}$ miles; from thence to Nutbrook $2\frac{1}{2}$ miles; from thence to Cromford canal 6 miles, with a total rise of about 100 feet from the Trent.

Exeter Canal, was probably the first pound-lock canal established in England, for we find that in 1563 the corporation of the city employed John Trew of Glamorganshire to form a canal, which should restore the navigation already rendered difficult in the river, in consequence of a weir constructed across it in the time of Henry III. The length of this canal was 9360 feet, the breadth 16 feet, and depth 3 feet; and several pools or chambers were formed, 300 feet in length, 80 feet in breadth at the top, and 50 feet at the bottom, with the sides walled for the purpose of passing the vessels; each pair of gates was 25 feet in height, and each leaf 20 feet in breadth, furnished with iron and brass work, that they might be moved with facility; specifications of the work remain among the papers of the corporation.

The most ancient method of navigating rivers was by flashes of land-waters, so collected that boats could be carried over the shoals: in this canal we find the first improvements were made by John Trew, who constructed a number of pools or locks, the vestiges of which may still be seen, consisting of the chamber-walls, partly buried in the western part of the canal, which was cut in 1699. In one of the specifications above alluded to is the following entry:—"for digging a pool between the said two gates, which must be 300 feet in length at least, and about 80 feet in breadth, at the top or surface of the water, and 50 feet broad at the bottom, and for walling the same on both sides, for the convenient and necessary passing of ships one after the other." These pools, or pylls, had each a pair of sluices, and were no other than pound locks, and frequent mention is made of these pairs of sluices in the several conveyances by the Corporation. There can be no doubt that on the whole canal there were at least seven sluices; the pools were fed by the river Ex, which had a stake weir constructed across it long before the one of stone.

After the works were executed, we find that the Corporation were by no means satisfied with Mr. Trew, for the canal could not be entered at all "tide and tides;" it was afterw a considerably deepened, and other sluices added.

The two Brothers of Viterbo, as we have already seen, had built a lock chamber, with a double pair of gates, at the Canal della Martesana, as early as 1481, and it seems extraordinary that so novel an invention had not found its way from Italy into England until more than 80 years afterwards: the canals in France for the purposes of irrigation may have suggested the idea of a sluice that could be opened for the passage of boats; Adam de Crapone, employed by Henry II. of France for these works, had, in all probability, seen the gates which shut the locks in Italy.

Previous to this discovery it was not possible to form an artificial canal, except in a perfectly level district, and we find attention at once directed to the improvement of inland navigation throughout Europe immediately afterwards; in the Low Countries and in Holland the greatest advantage was taken of the discovery, and a most complete system was established for the passage of vessels of very considerable tonnage.

Forth and Clyde Canal has its course from the river Forth, in Grangemouth harbour and passes the Loggie water by a stone aqueduct, and the Kelvin by another, when it locks down in Bowling's Bay. There is a branch to the Monkland Canal at Glasgow $2\frac{3}{4}$ miles in length. On this canal are thirty-three draw-bridges, ten large and thirty-three small aqueducts. There is a reservoir at Kelmananmuir, the area of which is 70 acres, which

has a depth of water at the sluice of 22 feet. Another reservoir at Kilsyth comprises 50 acres, and has a depth of 24 feet.

The aqueduct at Kelvin is in length 429 feet, and in height above the stream 65 feet; a small junction canal has been cut opposite the river Cart, which unites the Forth and Clyde with the river Clyde. The lock chambers are in length 68 feet in width, at the gates 15 feet, and in the centre 17 feet. The walls are curved and batter; the retaining

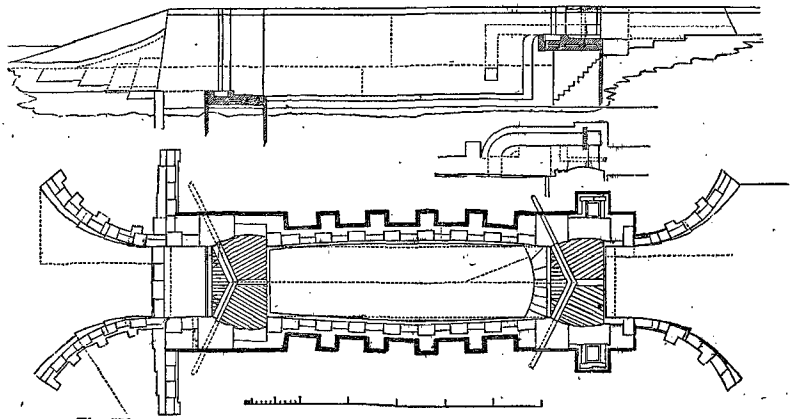


Fig. 550. PLAN AND SECTION OF LOCK OF FORTH AND CART.

walls are in freestone, coped with whinstone; they were puddled at the back to a thickness of 2 feet.

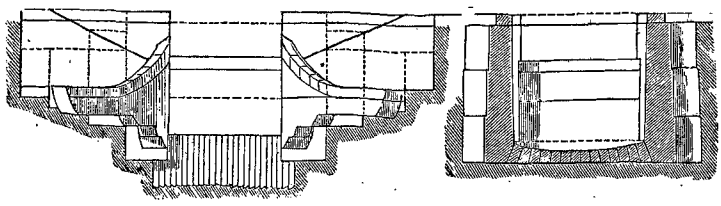


Fig. 551. ELEVATION OF TAIL. TRANSVERSE SECTION.

Foss Navigation commences near Newburgh Hall, 4 miles from Easingwold, and falls into the Ouse on the south side of the city of York.

Foss Dyke Navigation begins at Torksey on the Trent, and ends at Lincoln High bridge; it is level throughout. At Torksey is a double lock with gates pointed both ways, for the purpose of damming up the Trent, and keeping out the flood waters. At the other end is another lock, for preventing the water of the Witham from entering during the time of floods. Torksey being the site of a Roman town, it is supposed that this work was a continuation of Caerdike, made by the Romans; Domesday Book mentions the place as important.

Glamorganshire Canal, sometimes called the Cardiff, from commencing near that town on the Taff, near the place where that river enters the Penarth harbour, which river it crosses by an aqueduct, and terminates at Merthyr Tydvil.

Glasgow, Paisley, and Ardrossan Canal, begins at Port Eglington, west of the town of Glasgow, and terminates at Johnstone.

Glenkenns Canal runs from the Dee near Kirkcudbright, and terminates in Loch Ken, near Glenlochar bridge.

Gloucester and Berkeley Canal passes from the Severn, at Sharpness Point, and terminates near the city of Gloucester. This spacious ship-canal is level throughout, and capable of floating vessels of 400 tons burthen, there being at least 18 feet water. Near the outer harbour, in the Severn, is a breakwater.

An act of parliament was obtained for a ship-canal from the city of Gloucester to the open estuary at Berkeley Pill, in the year 1793, and the works were commenced under the direction of Robert Mylne, the architect of Blackfriars bridge, when a basin and entrance lock was made at Gloucester, and about 8 miles of the canal on the low ground was com-

pleted; but it was not until the year 1818, that it was proceeded with under the direction of Mr. Thomas Telford. The proposed entrance at Berkeley Pill being considered too much exposed to the south-west winds, it was determined that one should be formed under a projecting headland called Sharpness Point, where, restrained by a rocky shore on each side, the river channel was the only passage for the flux and reflux of the tide, thus securing deep water free from sand and mud banks, to which the flat shores of the Severn are subject.

An entrance basin and extensive piers of masonry were constructed, and by a large tide-lock the canal was raised to the same level as that of the Gloucester basin. Near the Sharpness Point, the canal is carried for the distance of a mile along the face of a very steep bank of rock marl; the outer bank being formed of and secured by a sea-wall.

In addition to the sea-lock, which admitted vessels of 300 tons burthen, another was constructed for barges of 70 or 80 tons. It is high water at spring tides at this entrance at 7 o'clock, and the depth upon the lock-sills is from 26 to 28 feet, at neap tides from 14 to 16 feet. The length of this canal is about 16 miles, its depth 18 feet; it is supplied with water from the river Frome.

Grand Junction Canal, one of the principal engineering works of Mr. William Jessop, forms an important link in the system of inland navigation, by which the capital is connected with the iron and coal fields of the midland counties. Within a mile of its commencement, it rises 37 feet to its first summit; this summit level is 4½ miles long, and has a tunnel 2045 yards in length, through which the canal enters the marlstone ridge of the lias formation; it then falls 60 feet into the valley of the Nene, and continues on a level for 13 miles to Gayton, from which place there is a branch to Northampton. On this level the famous Blisworth tunnel is situated, 3080 yards in length, which was completed in March, 1805. Its internal width is 16½ feet, the depth below the water-line to the inverted arch 7 feet, and the soffite or crown of the arch is 11 feet above the same line. The side walls are segments of a circle of 20 feet radius, the top arch one of 8 feet radius; the side and top walls are 2 bricks thick, and the bottom or inverted arch 1½ bricks. The mortar was composed of 1 bushel of Southam lime (blue lias) to 3 of good sand: 6 inches under the water-line on each side of the tunnel, slide rails of fir 5 inches square, to keep the barges off the walls are fixed by pieces of oak let into the wall below them; these rails project 9 inches from the wall, and at every 9 feet a chock of wood is fixed upon the rail for the bargemen to set their pole against. This tunnel was contracted for at 15*l.* 13*s.* for every running yard, the soil being a hard blue clay, interspersed with two or three thin rocks. Sufficient headings having been driven at the company's expense several years before, the same contractors were paid 10½*d.* per cube yard for excavating the deep cutting at one end of this tunnel, and 11*d.* per cube yard for the other. The expenses of driving the above headings was 36*s.* to 42*s.* 6*d.* per yard run; nineteen tunnel pits, some 60 feet in depth, were sunk for the use of the tunnel, which cost above 30*s.* including steining, for every yard in depth.

The canal next falls into the valley of the Ouse, where its level is 172 feet below that of the Braunston summit. Following the line of the Ouse, it passes close to the town of Stony Stratford, whence a branch goes off to Buckingham; it then continues to Linford Magna, Fenny Stratford, and Leighton Buzzard, through the sands and gault clay of the green sandstone formation, and rises to the summit level at Tring by a lockage of 192 feet: it attains this level near Marsworth, 51 miles distance from Braunston. The summit level, 3¾ miles in length, is carried through a chalk cutting of 30 feet in depth, and passing by Berkhamstead and Hemel Hempsted, the canal falls into the valley of the Colne, and continues by King's Langley and Harefield to Uxbridge. Near King's Langley is a deep cutting, on a level of the canal, 127 feet below the Tring summit. From Uxbridge it passes through a flat district, and after crossing the river Cran and Brent, terminates in the river Thames at Brentford. The total cost of this great undertaking was 2,000,000*l.* sterling: its entire length from Braunston to Brentford is 90 miles, the width of the canal at bottom is 28 feet, at the water surface 42 feet, and its depth 4 feet 6 inches: the length of the lock chambers is 80 feet, and their breadth 14 feet 6 inches.

The reservoirs which supply the canal at

	Locks of Water.
Daventry contains	7205
Drayton	1337
Marsworth	994
Stanhope End	2296
Tring	1016
Old Wilston (covers 40 acres)	1413
New Wilston	1413
Weston	1856

Each lock contains about 9000 cubic feet of water.

As these reservoirs are at various levels, steam-power is required to raise the water from one to the other. The principal engine at Tring is estimated as a 70 horse-power;

its consumption of coals is about 1½ cwt. per hour, with a 40 feet lift; this engine works at a pressure of 24 pounds, makes ten strokes per minute, and pumps up sufficient for eighty locks in 24 hours.

Mr. Jessop's estimate for the completion of this canal was nearly quadrupled; the following are the lengths and lockage, as stated on the map which accompanied this report:—

	Miles.	Furl.	Ch.	Feet.
From the Oxford canal to near Braunston Mill	0	7	3·20	37 rise.
From Braunston Mill to the end of Long Buckby parish	4	2	0·30	level.
From the end of Long Buckby to the end of Whilton parish	0	5	5·10	60 fall.
From the end of Whilton parish to Stoke	13	3	5·90	level.
From Stoke to the river Ouse	6	4	4·10	112 fall.
From the river Ouse to near Marsworth	25	1	6·	192 rise.
From Marsworth to near Cow Roast	3	6	0·50	level.
From Cow Roast to Two Waters	6	6	0·50	127 fall.
From Two Waters to near Langleybury	4	6	2·40	level.
From near Langleybury to the river Thames	23	6	5·60	268 fall.
	90	1	3·60	

There is a branch from Uxbridge to Paddington, level throughout and 20 miles in length, at which latter place is a basin 400 yards long, and 30 yards broad. The barges have generally square heads and sterns, flat bottoms, and carry 60 tons; there are some with sharp heads and sterns, which carry 25 tons.

Grand Union Canal unites the Leicester Union about 4 miles from Market Harborough to the Grand Junction, at Long Buckby.

Grand Junction Canal unites the Severn with the Bristol Channel.

Grantham Canal, from the town of that name to the Trent Bridge at Nottingham. There are two reservoirs, one of 20 acres, and 9 feet deep, at Denton; the other, of 60 acres, at Knipton, both executed under the directions of Mr. William Jessop.

Gresley Canal, from Apedale to Newcastle-under-Lyne.

Hartlepool Canal is a cut through the solid rock to a depth of 19 feet; its length is not more than 300 yards.

Hereford and Gloucester Canal, from Hereford to the tideway of the Severn at Gloucester. There are tunnels at Hereford, Asperton, and Oxenhall; the first 440 yards long, the second 1320 yards, and the third 2192 yards.

Horncastle Navigation begins in the Old Witham river.

Huddersfield Canal connects the river Calder, between a bridge called Coopers, and the river Colne to Huddersfield. Near Marsden there is a rise of 436 feet, made by forty-two locks; here its summit elevation is 656 feet above the level of the sea. It has afterwards a descent of 334 feet 6 inches, divided by thirty-three locks. The tunnel at Scout, through a sand rock, is 204 yards long, and that at Standedge, called the Marsden tunnel, is 5550 yards in length, 17 feet high, and 9 feet wide, with a depth of water of 8 feet; each of these has a towing-path. Mr. Outram was the original engineer, but Messrs. Clowes & Nicholas Brown were afterwards employed.

Hull and Leven Canal unites the Hull river with Leven Bridge.

Ivelchester and Langport Canal connects these two towns.

Kennet and Avon connects the Kennet navigation at Newbury with the Avon, where the latter river becomes navigable to Bristol. This canal at its highest elevation is 474 feet above the level of the sea. There are two aqueducts over the Avon.

Kidwelly Canal, from the harbour of that name.

Lancaster Canal has its commencement at Kirkby Kendal. The tunnel at Hincaster is 800 yards long, and that at Whittle Hills is 300 yards. The aqueduct of stone over the Lune is 51 feet above the level of the water, and has five arches of 70 feet span each. At Barkmill, the Leeds and Liverpool canal crosses it by an aqueduct 60 feet high. There are two others belonging to the Lancaster canal, one at Garstang over the Wyre, the other at Bethorn over the Beeloo. This great work was the first of the kind undertaken by Mr. Rennie, and established his reputation as an engineer.

Leeds and Liverpool Canal, uniting these towns, is one of the boldest works executed, particularly for the time; its rise to the branch of the Bradford canal is 155 feet 7 inches. It soon after crosses the Aire by an aqueduct of considerable length, and again rises 88 feet 8 inches. The Bingley locks at this place consist of five rises; and every boat requires five locksfull of water, which might be economised by dividing them. At Skipton the elevation of the canal above the waters of the Aire at Leeds bridge is 272 feet 6 inches. At Gargrave it again crosses the Aire by another long aqueduct. At Rainhill Rock it rises 411 feet 4 inches above the Aire at Leeds, which is its greatest height. At Foulbridge the great tunnel commences, the length of which is 1640 yards; the height is 18 feet, and the width 17 feet. Near the tunnel is a reservoir, comprising 104 acres, and containing

1,200,000 cubic yards of water. At Barrowford, it locks down 70 feet, then crosses Colne Water by an aqueduct. At Burnley there is an embankment 60 feet high, and 1256 yards long; and two aqueducts, one over the Broun, the other over the Calder: there is also a road under the canal. At Gannah is another tunnel, 559 yards in length. Another aqueduct crosses the Henburn, and at Grimshaw Park there is a fall of 54 feet 3 inches, by six locks. An aqueduct passes Roddlesworth Water, and at Cophurst Valley is another fall of 64 feet 6 inches, by seven locks. Near Kirkless there are twenty-three locks, which bring the canal down 214 feet 6 inches from the Lancaster canal to the Wigan basin; from thence there is a fall to Newburgh of 30 feet.

The Lady's Walk, Liverpool, to Leeds Bridge, is 127 miles, and has a lockage of 844 feet 6 inches, viz. from Leeds to the summit level 411 feet 4 inches, and then a fall of 433 feet 2 inches into the basin at Liverpool, which is 21 feet 10 inches above the Aire at Leeds, and 56 feet above low water in the Mersey.

To James Brindley and Robert Whitworth the engineering works upon this line were entrusted, and the manner in which the whole were executed deserves the highest commendation. The locks are formed to receive boats 70 feet in length, and with 14 feet beam, and the least depth of water in the canal is 4 feet 6 inches. By means of its water conveyance a communication is at once opened between Liverpool and Yorkshire, and agriculture is benefited by it to a considerable degree.

Leicester Navigation. — From its commencement, at the basin of the Loughborough canal, to its junction with the Leicestershire and Northamptonshire Union canal, there is a rise of 45 feet; the whole was superintended by Mr. William Jessop.

Leicestershire and Northamptonshire Union Canal. — Where this navigation commences with the Leicester, it is 175 feet above the level of the sea. It rises 160 feet to the tunnel at Saddington, and falls into the Grand Union canal at Gumley Hall.

Leominster or Kington Canal proceeds from the latter place at an elevation of 505 feet above the level of the sea. It crosses the Lugg by an aqueduct at Kingsland, and by another over the Rea passes the tunnel at Sousant, 1250 yards long, and unites with the Severn and the Stafford and Worcester canal. The tunnel at Pensax is 3850 yards long.

Leven Canal communicates with Kingston-upon-Hull.

Liskeard and Loe Canal terminates at Moorswater, 156 miles above the level of the sea.

London and Cambridge Canal has its commencement at Bishop Stortford canal; twelve locks raise it 72 feet, and there is a tunnel 340 yards in length; ten locks then descend to a second tunnel, 418 yards in length. At about 13½ miles from its commencement is a third tunnel, 704 yards long; the canal locks down by twenty-two locks the next 12½ miles. Eight other locks occur before it falls into the Cam at Clayhithe sluice. On the Whaddon branch are thirteen locks.

Louth Canal commences at the sea lock in Tetney Haven, and terminates in the river Ludd.

Macclesfield Canal proceeds from the Peak Forest canal, and joins the navigation from the Trent to the Mersey; it is 29 miles in length, and passes from the north end of the Harecastle tunnel, to the Peak Forest canal at Marple; it is 32 feet wide at the surface, 16 feet at the bottom, and 5 feet 4 inches deep. It continues to a little beyond Congleton, a distance of 10 miles, upon a level, where it rises 114 feet by eleven locks, which occupy in succession nearly a mile in length; the canal then proceeds on a level to Marple. The dimensions of the locks are 84 feet in length, and 7 feet 6 inches in breadth.

As this canal crosses several deep ravines, it was necessary to have ten considerable embankments, some of which are 80 feet in height. The aqueducts, whenever introduced, are of cast-iron. These works were executed in conformity with an act of parliament passed in 1825.

Manchester, Bolton, and Bury Canal has its commencement in the Mersey and Irwell navigation, where there is a rise of 68 feet 4 inches by six locks. After leaving the Salford basin, and proceeding some miles, it again falls by twelve locks; it crosses the Irwell by an aqueduct near Clifton Hall, and again near Bolton: there is a third aqueduct over the Roach.

Market Weighton Canal locks down into the Humber, opposite the mouth of the Trent, at the Fossdyke Clough.

Monkland Canal proceeds to Glasgow, where it joins the Forth and Clyde canal, at a point 156 feet above the level of the sea.

Monmouthshire Canal commences on the Usk river, near Newport: from Crynda Farm to Crumlin Bridge the canal rises 358 feet.

Montgomeryshire Canal has a lockage of 225 feet from Llanymynoch to Newton, where it unites with the Severn. The branch from Garth Mill was made by Mr. Josias Jessop, and has six locks, of 8 feet each; it is 15 feet wide at bottom, and 6 feet deep: the Guilsfield branch was by Mr. G. W. Buck.

Neath Canal commences near Abernant, and terminates in the river Neath.

Newcastle-under-Lyne extends to Stoke-upon-Trent.

Newport Pagnell Canal extends to the Grand Junction at Great Linford.

North Walsham and Dilham Canal commences at Wayford Bridge, and terminates at Altingham.

North Wilts Canal proceeds from Swindon, which is 345 feet above the level of the sea, to the Thames and Severn canal, at Weymoor Bridge.

Norwich and Lowestoft Navigation, improved under the direction of Mr. William Cubitt. The sluice and lock between the Lake Lothing and the sea had their foundations laid at 30 feet below the level of spring tides, and upon these the side walls were constructed. The substructions are 10 feet in thickness, 50 feet in width between the walls, and 450 in length, the whole built as an inverted arch, grooved and filled up solid to its chord line. The floor of the lock agrees with this line, and is 12 feet below the low water of spring tides. The lake was deepened by a dredging machine, which lifted from two to four tons per minute from depths of 10 or 12 feet.

Nottingham Canal unites the Cromford canal with the Trent, and has some collateral cuts. At Amsworth is a large reservoir, with a regulating, self-acting, sluice which lets out 3000 cubic feet per hour. This canal, executed under the direction of Mr. William Jessop, cost 75,000*l.*

Nutbrook, or Shepley Canal, extends from Shepley to the Erewash Canal.

Oakham Canal from the town of that name to the Melton Mowbray Navigation.

Oxford Canal begins at Longford on the Coventry canal, where it is 315 feet above the level of the sea; its summit level at Marston wharf is 387 feet: its termination is in the Thames at Oxford, where it is 192 feet above the level of the sea. Over the valley at Brinklow it passes by an aqueduct of twelve arches, each of 22 feet span, and at Casford and Clifton are two others. At Newbold is a tunnel 125 yards long, and another at Fenny Compton, 1188 yards long.

Peak Forest Canal begins near Ashton-under-Lyne, crosses the Mersey by an aqueduct 90 feet high, with three arches of 60 feet span each; then rises 212 feet by sixteen locks, and afterwards joins the Macclesfield Canal: there is an inclined plane of 515 yards long, and 204 feet fall.

Pocklington Canal commences on the river Derwent at East Cottingwith, and terminates at Street Bridge.

Portsmouth and Arundel Canal, from Ford to Chichester harbour. It is supplied with water from the harbour by a steam-engine. At the east end are two locks, one of 5, the other of 7 feet, and a basin at the termination at Portsea: from the main line of the canal in Chichester harbour to the canal at Cosham is 15¼ miles; to Portchester Lake it is 1¼ miles.

Regent's Canal unites the Paddington branch of the Grand Junction with the Commercial Road Basin, which locks into the Thames. It passes under the Edgeware Road by a short tunnel, and by another under White Conduit Street. By this canal the London and Liverpool are united. The locks have all double chambers. The tunnel at Maida Hill is 370 yards long, and the other at Islington 900 yards.

Rochdale Canal. — From the Calder navigation at Sowerby Bridge, it proceeds until it locks down in the Duke of Bridgewater's canal, at Castlefield, Manchester. It has several reservoirs, a tunnel of 70 yards in length, 8 aqueducts, and forty-nine locks. Its total rise is 275 feet, and fall 438 feet.

Rye, or Royal Military Canal commences near the castle at Sandgate, and terminates at Cliff End.

Salisbury and Southampton Canal, intended to unite these two places.

Sankey Canal commences at the mouth of Sankey Brook, in the Mersey, and terminates at St. Helen's. It has eight single locks of 6 feet fall each, and two double locks of 15 feet each; there are eighteen several bridges, and near St. Helen's is a tunnel; this was the second canal made in England, that at Exeter being the first.

Sheffield Canal connects that town with the river Dunn. It commences in the township of Tensley, passing by an aqueduct over the road to Attercliffe and Sheffield.

Shrewsbury Canal commences in Castle Foregate basin, and terminates in the Ketley canal; part of the ascent is by locks, and the other by inclined planes. At Langdon is the first aqueduct, of cast-iron, over the Tern. The inclined plane at Wombridge is 223 yards long, and 75 feet perpendicular fall.

Shropshire Canal. — From the Severn at Coalport to the Donnington Wood canal. It rises 207 feet by an inclined plane. At Windmill Farm is another inclined plane, of 120 feet. The summit of this canal is 333 feet above the Severn at Coalport, and 120 feet above the summit of the Shrewsbury canal. The inclined planes, introduced by Mr. William Reynolds of the Ketley iron-works, is an epoch in canal history; and the Shropshire canal passing over a rugged country with a great scarcity of water, the system usually adopted was not found practicable. On the banks of the Severn, up the face of a steep bank, an inclined plane, 350 yards in length, and 207 feet of perpendicular height, was constructed,

with a strong double railroad upon it, to receive boats with their carriages. When the boats arrive at this height, with their load of five tons, they pass along a level canal for 1¾ miles, and then descend by an inclined plane, 600 yards in length, and 126 of perpendicular height; they then, by another level line of canal, which is the summit, proceed to Rodwardine Wood inclined plane, which is 320 yards long, and 120 feet perpendicular fall. Other inclined planes succeed; the whole works were completed in 1792.

Somersetshire Coal Canal commences at Limpley Stoke, in the Kennet and Avon canal, and terminates at Paulton.

Staffordshire and Worcestershire Canal.—From the river Severn at Stourport, and unites with the Trent and Mersey navigation, near Haywood in Staffordshire. Aqueducts conduct it over the river Trent and Sow Penk, Smester and Stour; there are also three tunnels, one under the town of Kidderminster.

Stamforth and Keadby Canal, from the Don at Fishlake, to the river Trent at Keadby in Lincolnshire.

Stourbridge Canal.—From Stewponey on the Staffordshire and Worcestershire canal to Stourbridge.

Stafford-upon-Avon Canal commences at King's Norton, and at 6 miles from Birmingham joins the Worcester and Birmingham. It has four branches, one to the Tamworth quarries, 2½ miles long, another to the Warwick and Birmingham canal, 1¾ miles long, and one at Temple Grafton Lime Walks, 4 miles in length, and the other 1 mile in length to Aston Cantslow. Near Milepole Hill is a tunnel, 320 yards in length, and several small aqueducts.

Swansea Canal, from the harbour, where the Tawe river falls into the Pen Tawe.

Tavistock Canal, from the tideway of the Tamar, at Morwelham Quay Basin, to Tavistock. Under the Morwelham dam is a tunnel, 2646 yards long; this tunnel has 460 feet height of earth and rock above it. The locks are made for boats 12 feet 6 inches long, and 5 feet wide. At Crebar there is an aqueduct 200 yards long, and 60 feet above the river.

Thames and Medway Canal commences at Gravesend, and by a tunnel through the chalk, it enters the Medway at Frinsbury.

The chalk formation, through which this tunnel is driven, was by no means favourable to its execution: in some places it was found so soft that it crumbled before the miner, and in others so dense that it was necessary to blast it with gunpowder; where the chalk was mixed with veins of earth, it required a considerable number of stout yellow pine spars 9 inches in diameter to support it; these were frequently crushed beneath the weight to which they were opposed, and some serious accidents occurred. The thickness of the brickwork varied according to circumstances; at the summit of the tunnel it was 14 inches, and generally at the springing 18 inches. The space above the brick arch was filled in with chalk and lime mortar as the vaulting advanced, and the chalk above was pinned up as securely as possible.

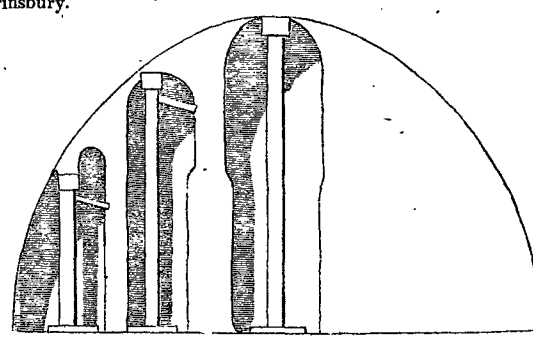


Fig. 552. THAMES AND MEDWAY TUNNEL.

The length of the tunnel is 2¼ miles, and the entire length of the canal nearly 7 miles; the passage round the Nore and up the Medway is thus avoided, and a distance of nearly 50 miles saved in the navigation.

Whilst this tunnel was in progress the water in the surrounding wells, for a very considerable distance, sank so low that it was necessary to deepen them to obtain a supply. When the salt water was admitted into the canal it affected all the fresh which pervaded the chalk district, and materially injured the quality of that which was drawn from the newly deepened wells, and great expense was incurred by the company, who were assessed in considerable damages for these injurious effects. The entrance from the Thames at Gravesend is through a basin; the canal is 50 feet wide and 7 feet deep to where the tunnel commences, a distance of 4¾ miles. Mr. William Tiernay Clark, the engineer, commenced the works in April, 1819. The width of water-way in the tunnel at top is 21 feet 6 inches, and at bottom 20 feet; the depth is 8 feet; the towing-path is 3 feet above the water, and 6 feet higher the footing of the brick arch, the clear width of which is about 30 feet; the occasional perpendicular shafts are 8 feet in diameter.

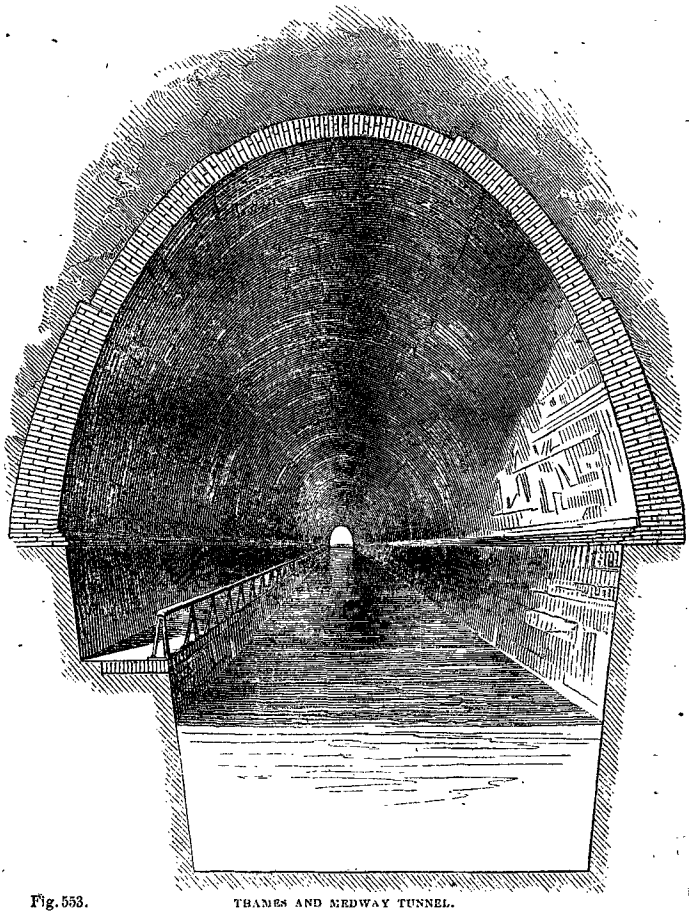


Fig. 553. THAMES AND MEDWAY TUNNEL.

Thames and Severn Canal, from the Stroudwater canal at Wallbridge, near Stroud; beyond Sapperton it passes the Tarlton tunnel, which is 2 miles and 3 furlongs in length; the span of the arch is 15 feet in the clear, and the highest point of the rock above it is 250 feet. In some portions masonry has been dispensed with, the rock being sufficiently hard to maintain itself. The canal passes the head of the Thames, and Sedlington St. Mary, where there is a branch to Cirencester. At Latton it is joined by a branch from the Wilts and Berks canal, and at Lechlade terminates in the Thames and Isis navigation.

Trent and Mersey commences at Wilden Ferry, where the Derwent joins the Trent; joins the Coventry and Fazeley canal at Fradley; at Haywood Mill the Staffordshire and Worcestershire canal; and at Stoke, the Newcastle-under-Lyne canal. It afterwards passes the Harecastle tunnel, 2880 yards in length, and is joined by the Macclesfield canal, and at Preston Brook unites with the Duke of Bridgewater's canal, and is then continued to Runcorn Gap, on the river Mersey. Mr. Brindley projected this canal, and commenced the works, which were completed by Mr. Henshall. There are altogether one hundred and twenty aqueducts, six tunnels, and ninety-one locks. The lockage from Harecastle summit to the Trent is 316 feet, and that from the summit of the Duke's canal is 326 feet.

Tetney Haven Navigation was projected by Mr. John Grundy, engineer, in 1761, when Mr. Smeaton was consulted upon the practicability of carrying it into effect. A navigable canal was to be formed from Tetney Haven to the upper end of Avingham-out-Fen, and from thence to join the River Lud, or Louth River, between Ringers Drain and Avingham Mill; and from thence, partly by the course of the river, but chiefly by a new canal up to the town of Louth.

Harecastle tunnel, upon this canal, was constructed by James Brindley, for a distance of 2888 yards, at a level of 197 feet from the highest summit of the hill above it. This

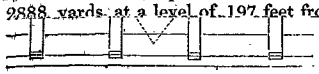
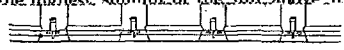


Fig. 554. ELEVATION OF TOWING PATH.



PLAN OF TOWING PATH.

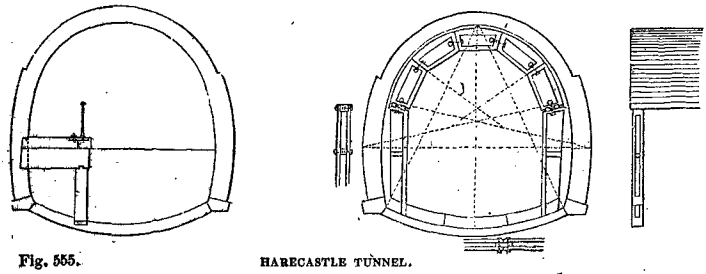


Fig. 555. HARECASTLE TUNNEL.

which 4 feet 9 inches is covered by the towing path, leaving 9 feet 3 inches for the passage of the boat; the path is supported by pillars, and the water flows under it. There are altogether fifteen shafts sunk from the surface, the deepest of which is 179 feet; they were so well set out, and the headings so accurately driven, that the whole length may be seen at one view.

The bricks were made from clay of superior quality, after being triturated by machinery; the mortar was of Barrow lias limestone, ground in a mill, and when set is quite impervious to water. The first brick was laid on the 21st of February, 1825, and the last on the 25th of November of the following year, and the whole was opened after not quite three years from the commencement of the works. The total number of bricks used was 8,814,000 in all, for shafts, culverts, &c. The total cost of all the works connected with this tunnel was 112,681*l.*

	£
Sinking 15 shafts 9 feet diameter	1,610
Driving heading through hill	7,057
Driving cross-heading to carry off water	470
Driving headings in coal measures to drain sand at north end	540
Excavating body of tunnel, turning brickwork, including timber, length 2926½ yards	43,435
Expense of towing path	9,600
Expense of railway, 6½ miles	7,000
Expense of providing bricks, mortar, centering	22,750
Labour upon mortar and centering	1,537
Carriage of materials	4,060
Expense of open cutting, entrances and turn-over bridges at each end, workshops, mills, engines, pumps, damages of land fences, &c.	14,622
	£112,681

River Witham Navigation, from the city of Lincoln through Boston, to its outfall into the sea, a distance of about 43 miles. The River Witham, from Lincoln to Boston, runs in a very crooked course, until it reaches the extensive fens of that district called Holland on the south, and Wildmore and West Fens on the north, and then passes through the high marshes into the great bay called Metari's Estuarium. This river was formerly navigable for large vessels, from its outfall at the Scalp to Boston, and from thence to Lincoln barges and other smaller boats could float at all times of the year. In the year 1744

surveys and levels were taken by the Messrs. Grundy, engineers, for the purpose of improving the drainage of the low lands consisting of 100,000 acres, and rendering the transit of trade with a declivity from Lincoln to the sea at $5\frac{1}{2}$ inches per mile; that all the living waters should be collected, in order to obtain a reflowing force capable of driving out any deposits left by the tides, by which means the outfall might be preserved open and clean; that the tides should not be suffered to flow into this new river, so that its depth and dimensions might be preserved. A lock, with two pair of doors pointing to landward for the purposes of navigation, and one pair pointing to seaward to keep out the tides, was provided.

Ulverstone Canal commences in Morecombe Bay at Hammerside Hill, and terminates at Ulverstone. At its entrance is a sea lock 112 feet long.

Warwick and Birmingham Canal commences at Saltisford, and unites with the Digbeth Branch of the Birmingham Canal near Birmingham. At Hatton is a rise of 146 feet by twenty locks. At Knowles Wharf there is a rise of 42 feet by seven locks; and at the Digbeth Branch is a fall of 42 feet by five locks. At Haseley there is a tunnel 300 yards in length, and another at Rowington. It crosses the Blythe River, the Cole, and the Rea by three aqueducts.

Warwick and Napton Canal proceeds from the Warwick and Birmingham in the parish of Budbrook, and terminates at its junction with the Oxford Canal near Napton-on-the-Hill. It crosses the Avon three times by aqueducts, viz. near Warwick Bridge, Radford, and Long Itchington.

Wey and Arun Junction Canal unites the Wey near Shalford Powder Mills with the Arun at New Bridge.

Wilts and Berks Canal begins at Abingdon on the Thames, and unites at Leamington with the Kennet and Avon Canal. The branch to Wantage is $\frac{3}{4}$ mile in length; the Longcot Branch $\frac{1}{2}$ mile, to Colne 3 miles 1 furlong, and that to Chippenham 2 miles. Where the canals lock into the Thames, it is 180 feet above the level of the sea.

River Weaver Navigation.—This river has its rise in the south-west part of Cheshire, and, after a circuitous course, falls into the Mersey at Runcorn, about 50 miles above Liverpool. From the western tide-lock on the Mersey to Winsford the distance is 24 miles, and the rise 52 feet only. There are 10 locks, each 80 feet in length, and 18 in breadth, and the vessels employed on this canal are from 60 to 70 feet in length, and 17 feet in breadth, drawing from 5 feet 6 inches to 6 feet 6 inches water, when loaded with about 70 tons. These works were all executed according to the conditions of an act passed in the year 1734.

In the year 1807, another act was obtained, and Mr. Telford employed to make a canal from near Frodsham Bridge to the Mersey at Weston Point, below Runcorn, a distance of 3 miles 6 furlongs.

The works which he executed were the protecting piers at Weston Point, a sea-wall about $1\frac{1}{2}$ mile in length, two river weirs at Winnington and Saltersford, and reconstructing the locks at Wetton Brook, near Northwich.

Fig. 556. SECTION OF WEIR AT SALTERSFORD.

Piers at Weston Point were constructed with the sandstone of the neighbourhood, and by their formation the entrance into the basin was extended, affording greater facility to vessels, both for entering and departing, than when the entrance was at a considerable distance from low water-mark. The cost of these protecting piers was 7835*l.*

Sea Bank.—For 2000 yards the canal skirts a steep bank exposed to the south-western gales, from a reach of upwards of ten miles of sea; and the original bank which protected the canal had its upper slope paved with rubble stone, pitched on edge without mortar; the waves worked into this, and softened the marl which formed the banks of the canal, causing the rubble paving to sink into it.

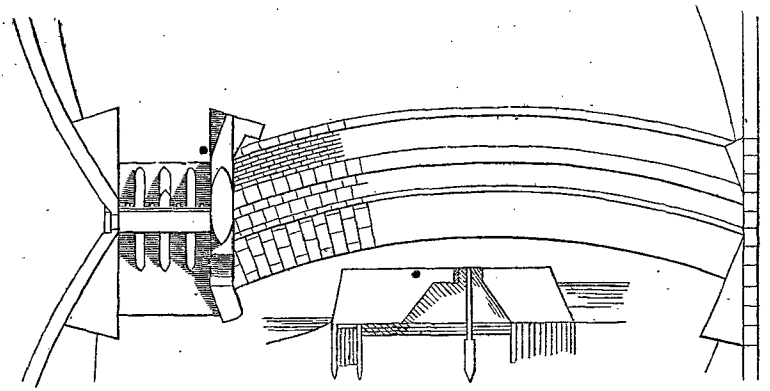


Fig. 557. SALTERSFORD WEIR.

Mr. Telford had the old paving broken into small masses, and laid in water lime mortar, well grouted, upon the banks after they had been shaped with the proper declivity.

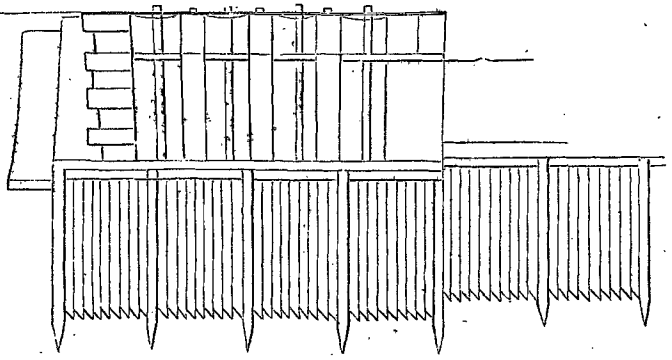


Fig. 558. ELEVATION OF SALTERSFORD WEIR.

Upon this bed of broken stone in mortar was set a pavement of scabled or roughly dressed stones, about 18 inches in depth; these were laid in mortar, and all the joints grouted well in, which no storms have penetrated or deranged. The whole cost was 17,000*l.*

Grand Western Canal has a contrivance which to a certain extent supersedes the use of the lock; this is by means of a lift, which has some advantages in the saving both of time and water. These lifts are 46 feet in height, and consist of two chambers, with a pier of masonry between them; they are of sufficient dimensions for each to contain a timber cradle, in which the boat required to ascend or descend is placed. The cradle, when on a level with the canal, allows the boat to swim into it, by simply raising up a water-tight gate at the end. The two cradles which work in the chambers, when full of water, or when either or both of them contain a boat, balance each other on very strong chains, which pass over three cast-iron wheels, and are so arranged that the water in the upper cradle is kept about 2 inches below that in the pond, which gives it a slight preponderance, sufficient to set the machinery in motion. It is necessary to pay particular attention to the strength of the materials. The boats in this instance weigh about 8 tons, and pass up and down the 46 feet in about 3 minutes, consuming 2 tons of water only, whereas in the ordinary way 3 tons would be required.

Wisbech Canal runs from the Nene river to the old river at Outwell.

Worcester and Birmingham unites Birmingham with the river Severn at Deglis, a little below Worcester. The tunnel at Westheath is 2700 yards long, 18 feet high, and 18 feet 6 inches clear width, with a depth of water of 7 feet 6 inches. The tunnel at Tardebig is 500 yards long; that at Shortwood 400; that at Oddingley 120, and that at Edgbaston 110 yards long.

Wyrley and Essington Canal, from Wyrley Bank to Birch Hill in the parish of Walsall: there are several branches from this canal; one connects the Coventry Canal, near Huddersfield, another Hayhead lime-works, another Lord's Hay, and another Essington Wood colliery.

Name of Canal.	Date.	Length.	Top Breadth.	Bottom Breadth.	Depth.	Total Rise.	Number of Locks.	Total Fall.	Number of Locks.	Length of Locks.	Breadth of Locks.	Length of Tunnels.	Length of Aqueducts.	Tonnage of Boats.	Engineer.
		miles	feet.	ft. in.	ft. in.	ft. in.		ft. in.		feet.	ft. in.	feet.	miles	tons.	
Aberdare	1793	6½	-	-	-	40 0									
Aberdeenshire	1796	18¾	23	-	3 9	169 0	17	-	-	57	9 0	-	-	-	Capt. George Taylor.
Aire and Calder	1699														
Aire	-	11	-	-	-	-	-	43 6	6						
Calder	-	12¾	-	-	-	-	-	28 3	4						
United rivers	-	18¼	-	-	-	-	-	34 6	4						
Canal to Selby	1788	5	-	-	-	-	-	-	1	60	18 0				
—— to Goole	1826	18½	60	40 0	7 0	-	-	28 9	-	70	19 0	-	-	-	Mr. Rennie.
Alford	1826	6⅛	-	-	8 0	7 9	1	-	-	-	-	-	-	-	Tierney Clarke.
Ancholme	1767	19⅛	-	-	-	6 0	1								
Andover	1789	22½	-	-	-	-	-	176 4	-	-	-	-	-	-	Robert Whitworth.
Arun (river)	1785	26¼													
Ashby de la Zouch	1794	26½	-	-	-	-	-	-	-	-	-	-	-	-	Robert Whitworth.
Ashton-under-Lyne	1792	-	31	15 0	5 0	-	-	-	-	70	7 0				
Avon (river)	1664	36													
Avon (river)	1751	43⅜													
Avon and Frome	1700	15⅓													
Barnsley	1793	15⅛	-	-	5 0	257 0	20	-	-	66	15 0	-	-	-	Mr. Jessop, Mr. Gott.
Basingstoke	1778	37	38	-	5 6	195 0	29	-	-	72	13 0				
Baybridge	1825	3⅝	28	-	4 0	14 0	2	-	-	-	-	-	-	-	May Upton.
Birmingham	1768	22⅝	-	-	-	19 9	3	132	21	-	-	-	-	-	Brindley.
Birmingham and Fazely	1783	20½	-	-	-	-	-	248							
Digbeth Branch	1783	1½													
Walsall Branch	1794	4¼													
Birmingham and Liverpool Junction	1826	39	-	-	-	-	-	174 9	27	80	7 6	-	-	-	T. Telford.
Blyth River	1757	9	-	-	-	-	4								
Borrowstowness	1768	7	-	-	7 0										
Bradford	1771	3	-	-	5 0	86 3	10	-	-	66	15 2				
Brecknock and Abergavenny	1793	33	-	-	-	68 0									
Bridgewater, Duke of	1737	73	-	-	-	82 0	10	-	-	-	-	-	18	-	Brindley.
Bridgewater and Taunton	1811	42⅓	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Rennie.
Britton Canal	-	4¼													
Bude Harbour and Canal	1774	45⅝	-	-	-	-	-	-	-	-	-	-	-	-	Edmund Leach.
Bure, or North River	1773	9	-	-	-	-	-	0 6							
Bure, Yare, &c.	1670	86½													
Caistor	1793	4	-	-	-	-	6								
Calder and Hebble	1758	22½	-	-	-	-	-	192 6	28	-	-	-	-	-	Smeaton
Caledonian	1803	23	40	-	20 0	94 0	27	-	-	180	40 0	-	-	-	T. Telford.
Carlisle	1819	11¼	-	-	-	70 0	9	-	-	-	-	-	-	-	W. Chapman.
Chesterfield	1771	46	-	-	-	335 0	65	45 0	-	-	-	-	-	-	Brindley.
Coventry	1768	37¾	-	-	-	-	-	-	-	-	-	-	-	-	James Brindley.
Crinan	1799	9½	-	-	12 0	58 0	7	59 0	8	-	-	-	-	-	Mr. Rennie
Cromford	1789	18	-	-	-	80 0	-	-	-	-	-	-	-	-	William Jessop
Dearne and Dove	1793	9½	-	-	4 6	127 0	24	-	-	53	14 4	-	-	60	Whitworth.
Derby	1793	9	44	24 0	5 0	29 0	-	-	-	90	15 0				
Dorset and Somerset	1796	40													
Droitwich	1768	5¾	-	-	-	59 6	8								
Dudley	1776	13	-	-	5 0	31 0	5	13 0	2	-	7 0	6325			
Edinburgh and Glasgow	1817	13	-	-	5 0	-	-	110 0	-	-	-	-	-	-	T. Telford.
Ellesmere and Chester	-	61	-	-	-	380 0	-	226 0	-	-	-	-	-	-	Brindley.
Erewash	1777	11¾	-	-	-	100 0									
Forth and Clyde	1768	35	-	-	-	155 0	20	156 0	19	74	20 6	-	-	-	Smeaton.
Foss	1793	12¼	-	-	-	47 8	-	-	-	-	-	-	-	-	William Jessop.
Foss Dyke	-	11													
Glamorganshire	1796	25	-	-	-	611 0									
Glasgow, Paisley, and Ardrossan	1806	11	-	-	-	102 6	-	64 0	-	-	-	-	-	-	James Jardine.
Glenkenns	1802	25¾	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Rennie.
Gloucester and Berkeley	1793	16½	70	-	18 0	-	-	-	-	-	-	-	-	-	T. Telford.
Grand Junction	1793	90	43	-	5 0	-	90	-	-	82	14 6	-	-	-	Mr. Barnes.
Grand Union	1810	45	-	-	-	-	-	-	-	-	-	-	-	-	Mr. R. Bevan.
Grand Western	1796	35													
Grantham	1793	33	-	-	-	197 6	-	147 6							
Gresley	1775														
Hereford and Gloucester	1791	35⅓	-	-	-	195 6	-	195 6	-	-	-	-	-	-	Joseph Clowes.
Hertford Union	1824														
Horncastle	1792	11													
Huddersfield	1794	19¾	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Outram.

Name of Canal.	Date.	Length.	Top Breadth.	Bottom Breadth.	Depth.	Total Rise.	Number of Locks.	Total Fall.	Number of Locks.	Length of Locks.	Breadth of Locks.	Length of Tunnels.	Length of Aqueducts.	Tonnage of Boats.	Engineer.
		miles.	feet.	ft.in.	ft.in.	ft. in.		ft. in.		feet.	ft.in.	feet.	miles	tons.	
Hull and Leven	1801	3	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Rennie.
Ivelchester and Langport	1795	7													
Kennet and Avon	1794	57	44	24 0	5 0	210 0	31	404 6	48	80	14 0	-	-	-	Mr. Rennie.
Kidwelly	1766														
Lancaster	1792	76	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Rennie.
Leeds and Liverpool	1726	108¾	42	27 0	5 0	-	-	-	-	70	15 6	-	-	-	Mr. Brindley.
Leicester	1791	14	-	-	-	45 0	-	-	-	-	-	-	-	-	William Jessop.
Leicestershire and Northamptonshire	1793	17	-	-	-	-	-	-	-	-	-	-	-	-	John Varley.
Leominster and Kington	1791	46	-	-	-	48 0	-	496 0	-	-	-	-	-	-	Thomas Dadford.
Leven Canal	1801	3	-	-	-	-	-	-	-	-	-	-	-	-	William Jessop.
Liskeard and Loo	1825	5⅞	-	-	-	156 0	25								
London and Cambridge Junction	1812	28¼	44	24 0	6 0	72 0	12	165 9	32	-	-	-	-	-	Mr. Rennie.
Louth	1763	14	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Smeaton.
Macclesfield Canal	1826	29½	-	-	-	113 9	-	-	-	-	-	-	-	-	Mr. Telford.
Manchester, Bolton, and Bury	1791	15	-	-	-	189 6	18								
Market Weighton	1772	11	-	-	-	-	-	-	-	-	-	-	-	-	Mr. Whitworth.
Monkland Canal	1770														
Monmouthshire Canal	1792	17¾	-	-	-	-	-	-	-	-	-	-	-	-	Mr. J. Dadford.
Montgomeryshire Canal	1794	27	-	-	-	-	-	-	-	-	-	-	-	-	Mr. J. Dadford.
Neath Canal	1791	14													
Newcastle-under-Lyne	1795	3													
Newport Pagnel	1814	1¼	-	-	-	50 9	7								
North Walsham and Dilham	1812	7													
North Wilts	1813	8½	-	-	-	-	-	58 6							
Nottingham Canal	1792	15													
Nutbrook, or Shepley	1793	4½													
Oakham Canal	1793	15	-	-	-	-	-	126 0							
Oxford Canal	1769	84													
Peak Forest Canal	1794	14½	-	-	-	-	-	-	-	-	-	-	-	-	Benjamin Outram.
Pocklington Canal	1815	8½	-	-	-	-	4	-	-	-	-	-	-	-	George Leather.
Portsmouth and Arundel	1817	14½	33	19 6	4 6	-	-	-	-	110	22 6	-	-	-	Mr. Rennie.
Regent's Canal	1812	8½	-	-	-	-	-	90 0	12	-	-	-	-	-	Mr. Morgan.
Rochdale Canal	1794	31	-	-	-	275 0	-	438 0	-	-	-	-	-	-	Mr. Rennie.
Rye, or Royal Military	1807	30	72	36 0	9 0	-	-	-	-	72	16 0	-	-	-	Royal Engineers.
St. Columb	1773	6													
Salisbury and Southampton	1795														
Sankey Canal	1755	12	48	-	5 7	-	-	78 0	10	-	-	-	-	-	John Eyes.
Sheffield	1815	4													
Shrewsbury	1793	17½	-	-	-	154 0	-	22 0	-	-	-	-	-	-	T. Telford.
Shropshire	1788	7½	-	-	-	-	-	-	-	-	-	-	-	-	Henry Reynolds and Henry Williams.
Somersetshire Coal Canal	1794	8½													
Staffordshire and Worcestershire	1766	47	-	-	-	294 0	-	100 6	-	-	-	-	-	-	Mr. James Brindley.
Stainforth and Keadby Canal	1793	15													
Stourbridge Canal	1776	5	28	-	5 0	191 3	16								
Stratford-upon-Avon	1793	23½	-	-	-	309 0									
Swansea Canal	1794	17	-	-	-	373 0	-	-	-	-	-	-	-	-	Thomas Sheasby.
Tavistock Canal	1803	4	16	8 0	3 0	266 6	-	-	-	-	-	-	-	-	Mr. John Taylor and J. Hitchins.
Thames and Medway	1800	8½	50	28 0	7 0										
Thames and Severn	1783	30	42	30 0	5 0	243 0	28	134 0	14	-	-	-	-	-	R. Whitworth.
Trent and Mersey	1766	93	-	-	-	-	-	-	-	-	-	-	-	-	Brindley.
Ulverstone Canal	1793	1½	65	30 0	15 0	-	-	-	-	-	-	-	-	-	Mr. Rennie.
Warwick and Birmingham	1793	22½	-	-	-	208 0	27	42 0	5						
Warwick and Napton	1794	14	-	-	-	134 6									
Wey and Arun	1813	18													
Wilts and Berks	1795	52	-	-	-	168 0	-	181 0							
Wisbech Canal	1794	6													
Worcester and Birmingham	1791	22	42	-	6 0	-	-	428 0	71	81	15 0				
Wyrley and Essington	1791	24	-	-	-	330 0	40	-	-	-	-	-	-	-	William Pitt.

Steam Engine.— The application of steam to draining, mining, manufactures, machinery, railroads, and navigation has so changed the labours of the civil engineer, that it is necessary to notice, however briefly, its inventors and progress.

Windmills are no longer employed to exhaust the water from our fens, nor are the rude constructions of complicated machinery under our bridges now required to throw up water to our houses. The miner is enabled to penetrate to greater depths in the bowels of the earth in search of the ore, and the civil engineer has an efficient agent on all occasions where great power is required; in the various operations of pile-driving, exhausting water, dredging and cleansing the bottoms of rivers or harbours, moving weights, and in constructions, it is equally important, and thus new elements have been introduced into his employment since the days of Perronet and Smeaton.

It is not necessary to give a detail of the various opinions relative to the invention of the steam engine; in the history of the progress of the useful arts none has been more keenly contested: different nations, as well as individuals, have put in their claims; but the efficacy of this useful machine depends on several physical properties, and on a variety of mechanical arrangements, to render them available; and suppose these all to have been known in the early age of science, they were not combined until James Watt devoted his mind to the subject: previous to this period, the steam engine possessed extremely limited power, and was inferior to other mechanical contrivances as a prime mover: but since his genius matured it, it has become the source of wealth to the British nation, as well as beneficial to the progress of civilisation and the comfort of the whole human race, and a monument to his fame. It must be evident that the engine as it now exists is not the exclusive invention of one individual, but the result of discoveries made during the two previous centuries: its progress from its commencement is a curious history, attesting the slow working of the human mind, and how long a period often intervenes before the genius springs up who can mature and render useful the so-called dreams of philosophers.

It is difficult to assign a time when the properties of steam first attracted attention; as early as 130 years before Christ we find some mention in the writings of Hero of Alexandria of a philosophical toy, called an æolipile, the principle of which was nearly the same as that which produces the motion in Barker's mill; in America, a few years ago, an engine was constructed of 21-horse power upon this system, and its only fault was stated to be the consuming too much fuel. This kind of engine was first made by Mr. Avery.

At the commencement of the seventeenth century Baptista Porta, who invented the camera obscura, gives in a commentary on the Pneumatica of Hero the design for a steam fountain, which raised water in a similar way to the steam-engine, the steam being formed in a separate vessel from that which contained the water to be raised.

A tube introduced the steam into the cistern, which was nearly filled with water, the end of the tube being above the level of the water; the steam occupied the space above the water, and by its elastic power forced the water through the bent tube.

Solomon de Caus, an engineer and architect in the employment of Louis XIII. of France, showed that water might be raised by the aid of fire higher than its own level; his publication is said to be the first instance in which steam is mentioned as a moving power.

In a copper ball, well soldered together, was a vent-hole, through which the water also entered, and a perpendicular tube, which approached nearly to the bottom of the ball, and was carefully soldered in. The ball, filled with water, and placed upon the fire, soon formed a quantity of steam, which having no escape pressed on the surface of the water, and occasioned it to mount in the perpendicular tube.

Giovanni Branca, an Italian engineer, formed a steam windmill, which seems to be one of the first instances of an attempt to render this power practically useful; and in a work published about 1629, there is a representation of this invention. It consists of a boiler with a spout directed towards a horizontal wheel, and the steam which issues from it is made to strike against the flat vanes or floats contrived on its circumference, producing a rotary motion in the wheel, which he proposed to transmit to machinery that should raise buckets, grind corn, &c. The specific gravity of steam being low, no great power could have been obtained by it when so applied; and being so rapidly condensed, and so much resisted by the air, which is twice its weight, its force could not be great.

Edward Somerset, Marquis of Worcester, who was confined in the Tower for being implicated in a plot at the time of the Stuarts, one day observing the lid of the pot in which his dinner was cooked suddenly fly off, asked his attendant, "What is to be done in such a melancholy den, unless we have the liberty of thought?" and probably this circumstance, trifling as it may appear, gave rise to his consideration of steam as a convenient motive power. In his Century of Invention, published in 1663, he shows "an admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards, for that must be, as the philosopher calleth it, 'intra sphaerum activitatis,' which is but at such a distance. But this way hath no bounder if the vessel be strong enough; for I have taken a piece of a whole cannon whereof the end was burst, and filled it three quarters full of

water, stopping and screwing up the broken end, as also the touch-hole, and making a constant fire under it: within twenty-four hours it burst and made a great crack; thus having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream 40 feet high; one vessel of water rarified by fire driveth up 40 of cold water: and the man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being attended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks." The Marquis called this a semi-omnipotent engine, and says he intended to have a model of it buried with him.

Sir Samuel Morland, in the year 1683, exhibited to Louis XIV. some new principles on the power of fire, by "which when water is evaporated, it will acquire a space equal to 2000 times what it was before; and that in such a state it might be made highly useful for raising water."

In the Philosophical Transactions for 1697 is a notice of a method for draining mines, where there is not the conveniency of a near river to play an engine, with air-pumps and cylinders connected by an air-pipe; which no doubt refers to the inventions of Denis Papin, a Frenchman, who first showed that a piston working tight in a cylinder might be raised by boiling a little water under it, and that by cooling and condensing the vapour which had raised it, a vacuum would be formed below, when the atmospheric pressure would force it down.

The first engine applied in England to practical purposes was made by Thomas Savery, for which he obtained a patent in the year 1698; and he suggested that it could be used for working mills, raising water to houses for domestic purposes, and extinguishing fires, supplying cities with water, draining fens and marshes, propelling ships, &c. This engine, though so highly creditable to the genius of its inventor, had some considerable defects, particularly in its application to the drainage of mines, the depths of which had been greatly increased; rendering it highly desirable that some process of working them, less expensive and difficult than that ordinarily adopted, should be resorted to.

The lift of Savery's engine was limited to 90 feet perpendicular, so that to raise water from the bottom of a mine it was necessary to place one at every 90 feet of depth; the water being successively raised into reservoirs, one above the other. It was also found that sufficient strength could not be given to an engine of this description, when made upon a large scale, and that the consumption of fuel was very great.

Thomas Newcomen, a blacksmith at Dartmouth, and John Cawley, a plumber of the same place, endeavoured to overcome the defects in Savery's engine, and to them we are indebted for the first atmospheric engine, for which they took out a patent in 1705. Here the piston was pressed down in a cylinder by the atmospheric pressure, a vacuum being previously formed below the piston, by filling the space with steam, which was then condensed. In this engine there were three principal parts; the boiler, which generated the steam, the cylinder, in which the steam was condensed, and the beam, whose movements followed the alternate admission and condensation of the steam, communicating the motion to the rod of the pump. An engine of this construction raised a load of 7 or 7½ pounds for every square inch of the surface of the piston.

This engine, which soon came into general use, received several improvements from Mr. Beighton, an engineer, who fixed a rod to the beam, called a plug-frame, with pins or catches in it, which opened and shut the valves with great precision and regularity; so that no attendant was required for that purpose, and the engine thus worked itself. The celebrated John Smeaton also applied all his knowledge in mechanics to proportion the various parts, which enabled him to construct machines of greater power, and to perform more work with the same amount of fuel. A crank and fly-wheel was added, which, from the reciprocating vertical motion of the piston, produced a continued circular motion.

The atmospheric engine had considerable advantages, arising from the almost unlimited power which could be commanded, which depended on the range of surface of the piston, from the low degree of temperature and pressure at which the steam was produced, so that there was little risk of explosion, from the simple mode by which the steam was condensed, and from the power which the engine possessed of opening and shutting its valves.

It had also its disadvantages, arising from the alternate heating and cooling of the cylinder, during which process a considerable quantity of steam was lost, and the air rushing in whilst the piston was under atmospheric pressure.

Newcomen's was, however, the first really efficient steam-engine applied safely and profitably to many very important purposes, and no doubt to it Mr. Watt was indebted for many valuable suggestions; it was exclusively used for sixty years, and, according to Mr. Carr, was the chief hydraulic engine for upwards of an hundred. In the coal mines it was universally adopted, as it was also in those of Cornwall, Cumberland, and elsewhere.

The great improvements made in the steam-engine by Mr. James Watt were condensing

the steam in a separate vessel; removing the air and water from the condenser by an air-pump; producing the movement by the aid of steam instead of atmospheric pressure; giving the piston an impulse or moving power both in ascending and descending; converting the alternate rectilinear motion of the piston into a continued circular motion, so as to adapt the engine for impelling machinery, and working the steam expansively, and thus greatly economising the fuel: this important engine, as completed by these and other improvements, soon superseded all other inventions of the kind, the principles which he established being those in use throughout the world at the present day. His first work is known as the single-acting steam-engine, in contradistinction to the double-acting engine, as it was afterwards called, in consequence of that beautiful arrangement which allowed the steam to enter alternately above and below the piston, at the same time forming the vacuum alternately, by which a moving force was communicated to the piston in its ascent as well as in its descent; thus constituting a continuous moving power.

To the genius and sagacity of James Watt the whole world owes a debt of gratitude; and Dr. Darwin, in his "Botanic Garden," has well asked, "Why, if at Rome a civic crown was given to him who saved the life of a single citizen, is not the projector of the steam-engine considered worthy of being covered with garlands of oak?"

Steamboat Engine. — About the year 1736, Jonathan Hulls took out a patent for "a new-invented machine for conveying vessels or ships out of or into any harbour, port, or river, against wind or tide, or in a calm." The power was procured by the pressure of the atmosphere against a vacuum, and, by some curious machinery, motion was given to a paddle-wheel, the continued rotation of which was provided for. This was probably the first attempt to apply the power of steam to navigation, and which has led to vessels so propelled crossing the Atlantic Ocean, and making the voyage to India.

In the year 1775, M. Perier had a small steamboat on the Seine, and seven or eight years afterwards the Marquis of Jouffray constructed one at Lyons, 140 feet in length, and 15 feet in width, which navigated the Saone for some time: about the same period they were introduced into Scotland as canal boats, and on the Forth and Clyde canal there was one which plied with much success. But it was not until Mr. Fulton, an American, had studied the subject, that a really efficient vessel was built; in the year 1807 he launched one at New York, containing an engine made by Bolton and Watt for the purpose, and a voyage was performed between that city and Albany, a distance of 160 miles, in thirty hours.

After Fulton had shown that steam might be applied as a moving power to ships, numerous other attempts were speedily made, and the first steamboat in Europe, after the appearance of Fulton's, was "The Comet," which plied between Glasgow and Greenock. "The Great Western," built expressly to cross the Atlantic, had two engines, each of 225 horse-power; her burthen 1340 tons; her paddle-wheels made 273,000 revolutions; her consumption of coal was $1\frac{1}{8}$ tons per hour. "The British Queen," of 1862 tons, since employed in the Atlantic navigation, had the diameter of the paddle-wheels 30 feet, and the power of her engine was 500 horse.

These large vessels usually make the voyage from Falmouth to New York in seventeen or eighteen days, their least speed being 89 miles per day; and the average for the whole voyage has been 190 miles daily.

Locomotive Engines. — After the great improvements made in the steam-engine by Mr. James Watt, those of high-pressure ceased to be generally used by manufacturers; but in the patent obtained in the year 1784, he explains that his newly-invented engine was calculated to propel carriages; and the manner by which he proposed to effect this was, by having a boiler made of wood, like a cask, to contain in the inside an iron furnace, which was to be entirely surrounded by water: this simple apparatus was to be placed on a carriage, and the wheels worked by means of a piston, the reciprocating motion being converted into a rotary one by toothed wheels and a sun and planet motion. The wheels differed in their proportions, in order that the variable resistance offered by the road might be more easily overcome. The cylinder was to be 7 inches in diameter, the length of the stroke 12 inches, and the number per minute 60. This carriage was to carry two persons, but it was never executed, as the inventor always manifested an objection to high-pressure steam.

In the year 1802, a patent was taken out by Richard Trevithick for a locomotive carriage; this was the first attempt to adapt the power either to the common road or a railroad, and its principle was high-pressure. The carriage had two small wheels in front, which served the purpose of guiding it, and two larger ones behind, by which it was driven. The cylinder, boiler, and fire were all enclosed in a case, and placed low down in the rear of the axle, and the large wheels could either be worked together or singly, or one could go one way whilst the other moved in an opposite direction; their motion was produced by a spur-gear, which had a fly-wheel added to it. The piston rod, outside the cylinder, was double, and drove a cross piece, working in guides on the opposite side of the cranked axle to the cylinder, and the crank of the axle revolved between the double parts of the

piston-rod. To this axle was attached the first of the toothed wheels, and to the axle, on which were the driving wheels, was the other, similar in size to the first, and worked by it. The steam cocks were open and shut by a connection with the crank axle. The force-pump, by which a supply of hot water contained in the casing which enclosed the cylindrical fire-box, &c., was injected into the boiler, was also worked from it, as was a pair of bellows.

Two years afterwards he obtained another patent, in which he specified the boiler as cylindrical, with flat ends, and an engine was built in conformity to it, which worked on a tram-road at Merthyr Tydvil, in South Wales. The wheels, though quite smooth, were found to have sufficient adhesion when the carriage drew ten tons of bar-iron, and its supply of coals, at the rate of five miles an hour.

In the year 1811 Mr. Blenkinsop took out a patent for the first double-cylindered engine. Here the boiler was circular, and the tube, which was connected with the fire, passed through the centre, and was bent up, to form the chimney. The cylinders, partly in the boiler, were vertical, and 8 inches in diameter. The piston rods worked the connecting rods by means of cross heads; the two cranks were placed below the boiler, and made to work two shafts fixed across the engine, on which were small-toothed wheels, working into a larger one between them.

On the axis of this, and outside the framing, were the driving wheels, one of which was toothed and worked in a rack on one side of the railway: there were two pair of plain-flanged wheels, one before, and one behind, the driving pair. This engine weighed 5 tons, drew 94 tons on a level at 3½ miles per hour; its consumption of water per hour was 50 gallons, and of coal 75 pounds.

In the following year another patent was taken out by the Messrs. Chapman, in which mention is made for the first time of fanners to excite combustion, but we have no account of the idea being carried into effect.

Numerous patents were taken out at various times by Mr. George Stephenson, Mr. Locke, and others, none of which were practically applied until April, 1829, when the directors of the Liverpool and Manchester railway offered a premium of 500*l.* for the best locomotive engine. It was to draw on a level plane three times its own weight, at the rate of 10 miles per hour, which weight was not to be more than 6 tons. The price of the engine was restricted to 550*l.*, the height of the chimney to be 15 feet, and the pressure on the boiler to be 50 pounds per square inch: it was to consume its own smoke; the whole weight of boiler and engine was to be supported on springs, and if the weight exceeded 4½ tons, the engine was to have 6 wheels.

In October the trial was made by three competitors, who owned the "Rocket," the "Novelty," and the "Sans Pareil;" the ground chosen was on the Manchester side of Rainhill Bridge, about 9 miles from Liverpool, where the road was level. The "Rocket," the production of Mr. Robert Stephenson, the engineer of the London and Birmingham railway, was the only engine which performed the required distance of 70 miles with the given load and at the stipulated speed. It was constructed with four wheels not coupled; the boiler was 6 feet long and 3 feet in djameter, and contained twenty-five copper tubes, 3 inches in diameter, through which the heated air from the furnace passed to the chimney.

The furnace at the after end of the engine was 2 feet wide, and 3 feet high; it had an external casing, between which and the fire-box was a space of 3 inches filled with water, and communicating with the boiler. The cylinders were placed on each side of the boiler, in an angular position, one end being nearly level with the top of the boiler at its after-end, and the other pointing towards the centre of the foremost or driving pair of wheels, with which the connection was made from the piston-rod to a pin on the outside of the wheel. The weight of the engine was 4 tons 5 cwt. The prize was of course awarded to Mr. Robert Stevenson, and from this time we may date the successful application of locomotives to railroads.

Prior to this competition the greatest load drawn by locomotives was 43¼ tons, engine and tender included, 15 tons at 10 miles an hour, or 28¼ tons of goods, including waggons, while the "Rocket" and tender, weighing only 7½ tons, drew 44 tons gross, at the rate of 14 per hour: this great result is principally to be attributed to the introduction of tubes in the boiler, by which the evaporating power was increased to three times that of the older engines, with 40 per cent. less consumption of fuel, the invention of Mr. Seguin. Since the period above alluded to numerous patents have been taken out for improving almost every portion of the locomotive engine.

Railways.—Iron railroads were not in use much before the commencement of the 17th century: previous to that time we find wooden rails employed at the coal works near Newcastle, where one horse was enabled to draw 4 or 5 chaldrons in carts, with four rollers fitted to the rails, on which they ran with ease. These roads were about 6 feet in breadth: across them oak sleepers were laid from 4 to 8 inches square, at a distance of 2 or 3 feet apart; on their ends, the only parts perfectly squared, longitudinal timbers were pegged down, 6 or 7 inches in breadth, and 5 inches in depth, extending the whole length of the

way, at about 4 feet distance from each other. This single road required frequent repairs, causing constant impediments to the carts; another rail was therefore added to that pegged upon the sleepers, and as this upper rail wore away it was kept renewed. Between the rails the roadway was made level with the tops of the sleepers with ashes, so that they were in some degree protected from the horses' feet.

Cast-iron rails were substituted for wooden at the Norfolk colliery, near Sheffield, about the year 1776, and were, perhaps, the first plate rails on record; they were secured to the wooden sleepers by nailing only, and it does not appear that stone bearers for the ends of the rails were used before the year 1800. We have an account also of a railroad laid down as early as 1767 at the Colebrooke Dale iron-works, where cast-iron wheels, turned in a lathe, were applied, when it was soon discovered, that if these were running on a pair of iron plates, a great advantage would be obtained over those employed upon common roads.

The plates were at first of cast-iron, very flat and smooth on the upper surface to receive the wheels, but having a flanch or feather rising vertically on one side, for the purpose of guiding them, which were cylindrical, and preventing them from getting off; these were sometimes placed on the inner, and sometimes on the outer edge of the rails, most generally on the former.

Another variety of rail was afterwards made use of, without vertical flanches, the flanch being formed upon one side of each wheel, and the wheels arranged in pairs upon the same axle, so that the flanches embraced the two parallel rails, or they were placed inwards and fitted between the lines of rail.

Wrought-iron bars were then adopted, 2 or 3 inches in width, and ¾ of an inch in thickness, lying upon longitudinal sleepers of timber, and fastened by spikes or bolts, upon which ran similar wheels to those last described.

Cast-iron bars were next introduced, with their edges upwards, on which ran cylindrical wheels, with either a flanch or groove around them, to keep them on the rail. These and a variety of other methods were adopted until the present edge-rail superseded all others. Mr. Jessop used this rail at Loughborough in Leicestershire, and instead of nailing the ends of the rails, he united them in a block of cast-iron, made to receive them, which was called a chair; these were placed upon stone blocks firmly fixed in the ground.

In October, 1820, a patent was obtained by Mr. John Berkinshaw of the Bedlington iron-works, Durham, for an improvement, capable of extensive application, which was that of forming rails of wrought-iron, by passing them when red-hot through rollers grooved in the required form; by this means wrought-iron bars, with rounded tops of any form, with flanches, may be produced in lengths of 18 feet or under, and when fixed on chairs 3 feet distance from each other make an admirable and permanent railroad.

Mr. Blenkinsop was the first to introduce the locomotive at the collieries in the north of England: one wheel of the engine had strong cogs or teeth around its periphery, which fitted into a toothed rack on the rail; this was considered necessary to prevent the wheel from slipping or turning round without advancing.

In 1829 the directors of the Manchester and Liverpool line employed Mr. James Walker and Mr. Rastrick to enquire whether it were possible to use the locomotive on a public railroad, and a very valuable report was made upon the power of such engines, the quantity of work they are capable of performing, their consumption of fuel, their annual cost, the friction of ropes in stationary engines, the cost of such ropes, the wear and tear of waggons, the accommodation to the public, and the comparative safety of the two modes.

In the year 1830, when the London and Birmingham was projected, it was considered that one line of rails would be sufficient for the traffic, and that the whole might be constructed for 6000*l.* per mile; it was at first intended that the carriages should be drawn by horses at the rate of 8 miles per hour. Fifteen years' experience has shown how little the success which has attended railway transit was then anticipated; since that time more than 73,000,000*l.* sterling has been expended upon the leading lines, the interest of which at 5 per cent., requires that the profits should not be less than 10,000*l.* per day. Five times that capital will be required to complete the various railroads now in progress, and those projected. The power of steam has triumphed over the prejudices which obstructed the progress of the first speculations, and it is now generally admitted that railroads are not only necessary, but indispensible; and when a system, uniting public utility with safety, and founded on integrity, shall be established over the whole of Great Britain, the price of the necessaries of life will no doubt be rendered more equal, intelligence will be spread, and the arts of civilisation carried through the length and breadth of the land.

The execution of railways has called into active employment a very different class of men from those engaged in repairing the common roads, and the artizans who manage the steam power, and superintend the property of the companies, are far more intelligent than were the great mass of attendants on the old system. All the arts of construction have been essentially improved; new principles have suggested themselves, and other materials have been made use of: iron has been wrought into every possible form, and its strength tested to serve the purposes of the railway engineer; the carpenter has exerted his skill to perfect the works with which he was entrusted, and many novelties have been introduced in the art

of framing; he has applied timber and iron in conjunction to roof in buildings of a span which some years since would have seemed to defy his power. The mason and bricklayer have revived the principles of skew arches adopted by the Romans, and in some instances improved upon them, and a beneficial impetus has been given to every branch of the building art. Other sciences have participated in these advantages: in geology many new facts have been brought to light from the deep cuttings and tunnels driven through the hills and mountains. It is scarcely possible to enumerate the advantages which the country has already derived from these works, and it would be daring to prophesy what may be the result of a more perfect system. Had the great success attendant upon railways been foreseen, and an accurate survey made of the levels throughout the whole of Great Britain, vast sums might have been saved, the lines would have been laid down more in unison with the general benefit, and due attention would have been paid to any future or branch lines that might have been required.

To detail all the engineering works upon the various lines would require volumes, and all that can be done is briefly to enumerate those executed, with such observations on their length, gauge of rail, and cost as could be obtained: the government has been careful in providing for the public, and numerous acts of parliament have been framed; the first was passed in 1838, to provide for the conveyance of the mails by railroads; the next which received the royal assent was in August, 1840, for the better regulation of railways. This important act determines that no railroad shall be opened to the public until a month's notice has been given to the Board of Trade, and that all railway companies shall deliver returns of the traffic in passengers according to the several classes; also of cattle and goods, as well as accidents on the line, and a table of tolls and charges. A third act received the royal assent in July, 1842, which was for the better regulating of railways, and for the conveyance of troops.

Another very important act received the royal assent in August, 1844, which attached certain conditions to the construction of future railways authorised or to be authorised by any act of the present or succeeding sessions of parliament, and for other purposes in relation to railways. This act, called Mr. Gladstone's, provided, that if after twenty-one years from the passing of the act for the construction of any future railway, the profits shall exceed ten per cent. the Treasury may revise the scale of tolls, and fix a new scale upon three months' notice being given: it also empowers the Lords of the Treasury to appoint an inspector, and to examine the accounts of any company, and ensures a daily train each way to carry passengers for one penny per mile, the average rate of speed being twelve miles an hour for the whole distance, including stoppages: such train to take up and set down passengers at every station: the carriages to have seats, and to be covered, and half a hundred-weight of luggage to be allowed to each passenger. It also stipulates that the Lords of the Treasury shall have electrical telegraphs laid down at the sides of the railway, to which several other useful provisions are added.

The Surrey Iron Railway Company, was the first incorporated by act of parliament, and passed in 1801. Its length is nine miles, and the cost of its construction was about 60,000*l.*; it had a double line of rails throughout the whole line, which extended from the town of Wandsworth to Croydon, with a branch to Carshalton. This railway was not intended to convey passengers; and horses were employed as the motive power.

The Caermarthenshire Tram-road was commenced in the year 1802; it is 16 miles in length, extending from the lime works of Castell-y-Garreg to Llanelly.

Sirhowey Tramroad extends from the Monmouthshire canal, near Newport, to Sirhowey furnaces, a distance of 11 miles.

Croydon, Merstham, and Godstone Railway was a continuation of the Surrey railway; its length was nearly 16 miles, and is said to have cost 90,000*l.* The line was double throughout, with a pathway on each side, 24 feet in width.

Oystermouth Railway proceeds from that place to the town of Swansea, a distance of 6 miles.

Kilmarnock Railway is in length 9¾ miles, and extends to Troon.

Bullo-pill, or Forest of Dean Railway, is in length 7½ miles; it commences on the Severn, near the town of Neconham; there are three short lines to various coal-mines in the forest.

The Severn and Wye Railway connects the two rivers; the extent, including its nine branches, is 26 miles.

Monmouth Railway proceeds from that town to a place in the Forest of Dean, called Howler Slade.

Berwick and Kelso Railway has never been completed, but was intended to unite the town of Berwick with Kelso.

The Hay Railway is in length 24 miles, through a mountainous district; it commences on the Brecknock and Abergavenny canal, and terminates at Parton Cross in Herefordshire.

Llanfihangel Railway is 6½ miles in length, commencing on the same canal, and ending at Llanfihangel Crucorney, in Monmouthshire.

The Grossmont Tramroad is about 7 miles in length, and has a rise of 166 feet. It commences at the Llanfihangel railway, and terminates at Llangua Bridge.

Penrhynmaur Railway, a little more than 7 miles in length, commences at that place, and terminates at Red Wharf, near Llanbedrgoch, in the county of Anglesea.

Mamhilad Railway, after a course of 5 miles, ends at Usk Bridge, in the county of Monmouth.

Gloucester and Cheltenham Railway extends from the basin of the Gloucester and Berkeley canal to the Knapp toll-gate at Cheltenham, the distance being 9 miles.

Mansfield and Pinxton Railway, 8¼ miles in length, commences at the first mentioned town, and ends near Alfreton, in Derbyshire, after passing through a country abounding in minerals.

Kington Railway is 14 miles in length, and may be considered as a continuation of the Hay railway, which it joins at Parton Cross, in Herefordshire; it passes by Kington, and terminates at Burlinjob, in Radnorshire.

Plymouth and Dartmouth is in length altogether 30 miles: this railway commences at the Sound at Sutton Pool, and terminates near the prison at Dartmoor, in the parish of Lydford.

Stratford and Moreton. — This tramroad is in length 16 miles, exclusive of a branch of 2½ miles; it extends from Stratford-upon-Avon to Moreton in the Marsh, the branch leading to Shipston-upon-Stour, in Worcestershire.

The above railroads were established solely for the use of miners, or the transport of coals and minerals, and some for that of merchandise. We now arrive at the period when it was considered that they might be rendered available for passengers.

Stockton and Darlington Railway, being the first on which the locomotive steam-engine was employed, excited considerable interest, and led to the great changes which have taken place in the transit of passengers, and the establishment of the numerous lines which have since been laid down. Its length was 25 miles 30 chains; it was opened throughout in September, 1835: it commences on the left bank of the Tees at Stockton, and proceeds in a southerly direction for 4 miles, where there is a branch to Yarm Bridge; the main line turns to the west, and afterwards to the north-west, by the town of Darlington, from whence its course is nearly north, to the point of junction with the Clarence railway. It then passes West Auckland, and ends at Bishop Auckland. The main line has five branches, making together 15¼ miles, the whole extent being 40 miles. At the fifth branch, which extends across the river Tees, is a suspension bridge, 240 feet in length between the piers, and 30 feet above low water-mark. The gauge of the way is 4 feet 8½ inches, ruling gradients 1 in 104, rise in feet per mile 50, and cost per mile 9000*l*. The total sum expended to July, 1844, was 450,000*l*.

Durham and Sunderland, open throughout 28th of June, 1839, is in length 13 miles 20 chains; its termini are in the two towns above named; the gauge of way is 4 feet 8½ inches, ruling gradients 1 in 60, rise in feet per mile 88, and cost per mile 14,281*l*. The total sum expended to August, 1844, was 301,248*l*., and the cost of working the previous six months 11,334*l*.

Redruth and Chasewater Railway. — The length of the main line is 9¼ miles, and that of the four branches rather more than 5 miles additional. It commences at Redruth in Cornwall, and ends at Point Quay, in the parish of Feock.

Monkland and Kirkintilloch is 10 miles in length, with a branch of about ¾ mile. It commences at Palace Craig, and terminates at Kirkintilloch, in Dumbartonshire.

Rumney Railway is in length 21¾ miles, and extends from Bedwelty, in the county of Monmouth, to Bassaleg, in the same county.

West Lothian, with its two branches, is in length 23 miles; it commences at Ryall, on the banks of the Edinburgh and Glasgow Union canal, and ends at Shotts.

Cromford and High Peak Railway, originally planned by Joseph Jessop, was executed under the direction of Thomas Woodhouse, engineer. An act was obtained in the year 1825, having for its object a junction between the Cromford and the Peak Forest canals, through a very mountainous and rugged district, where many obstacles occurred to prevent its being effected; the railway was substituted in lieu of it.

As Derbyshire is intersected by a lofty range of mountains, which extend northerly into Yorkshire and southerly into Staffordshire, the waters which run to the eastern and western coasts are divided, and over these mountains, which are of a limestone formation, the railway is carried: it ascends to a level of 992 feet above the Cromford Canal, and 1270 feet above the level of the sea. The railway commences at the Cromford Canal, where it ascends, by two inclined planes, to an elevation of 465 feet; the lower one being 580 yards long, rising 204 feet, the upper one 711 yards long, and rising 261 feet. Each of these inclined planes has two stationary steam-engines of 20 horse-power, which work endless chains, directed and supported by pulleys, for the purpose of drawing up the waggons, two of which, containing five or six tons each, are drawn up at a time, with a velocity of four miles an hour: 123,000 cubic yards of excavation, principally through grit or free-

stone rock, were necessary for the execution of this portion of the work. The railway proceeds from the top of the upper plane for a mile nearly level, after which, at Middleton, it mounts another inclined plane of 253 feet rise in 708 yards: here the cutting was sometimes 43 feet in depth, through a solid limestone rock, where it was necessary to remove 32,000 cubic yards, and the waggons were again drawn up by means of two other engines of 20 horse-power each. The railway continues level from thence, and at the distance of a mile the limestone rock is cut through to a depth of 68 feet. In the centre of these cuttings there is a tunnel of arched masonry 105 yards in length, and the Via Gellia embankment was formed out of these cuttings, which amounted to 168,000 cubic yards. At the end of the embankment the Hopton inclined plane commences, which rises 98 feet in 457 yards, where are two other stationary steam-engines: there is then a level for 12 miles, with the exception of 2 miles, which have a rise of 10 feet each, in order to lessen the depth of cutting at Haven Lodge.

The chief cuttings in this length were, Carsington, 20,000 cubic yards; Bressington, 58,000; the Minington embankment, 78,000; Pike Hall and Burncliff, 40,000 yards; the cutting near the Manchester road and Haven Lodge, 125,000 cubic yards; and at the Hurdlow inland plane, 38,000 cubic yards: most of these cuttings were through limestone rock, and were blasted with gunpowder, the material being applied to form the several embankments.

At 16 miles from the commencement, the railway ascends by the Hurdlow inclined plane to its greatest elevation; this plane rises 168 feet in a length of 850 yards: there are two engines of 10-horse-power each. It then continues level for nearly 20 miles, and the excavations in this length were, at Hurdlow and Brierlow, 57,000 cubic yards; at Hindlow, 26,000; at Hill Head and Harpur Hill, 44,000; south of Turncliffe, 46,000; north of Turncliffe, 47,000; and at Ladmanlow and Burbage, 62,000 cubic yards.

At Buxton there is a tunnel 580 yards long, 21 feet in width, and 16 feet in height; this was driven from the two ends, without any pit or shaft being sunk; the strata passed through was hard clunch or shale, to remove which gunpowder was employed. The whole of the tunnel is arched with masonry.

At Upper Goyt is another inclined plane, which descends 266 feet in a length of 660 yards; and the lower plane descends 191 feet in 455 yards, which brings the railway into the valley of the river Goyt. Here are two engines of 20-horse-power each, and the excavations were about 30,000 cube yards. After this, there is a level of 2¼ miles, which was effected by 74,000 cubic yards of cutting. To this succeeds the Shallcross inclined plane, 817 yards in length, with a descent of 240 feet, where there are two other engines, of 20-horse-power.

At Whaley is another inclined plane, falling 42 feet in a length of 180 yards, which required a cutting of 18,000 cubic yards; here the railway, after having traversed 33 miles, communicates with the Peak Forest Canal.

There are altogether fifty-two bridges, some of which are cast-iron. The cast-iron rails were in 4-feet lengths, having a pedestal at one end, and the opposite end adapted to it, which admits of a little movement at the joint; each rail weighed 84 pounds; so that for a mile of single road about 100 tons of rail were required.

The cost of completing the railway was 150,000*l.*, and of the engines, reservoirs, and machinery, 30,000*l.*

Nantle Railway joins the town of that name to the shipping quay at Caernarvon.

Portland Railway is in length 2 miles; it commences at the Priory Lands, and terminates at the castle.

Duffryn Llynvi and Port Cawl Railway is in length 16¾ miles; it commences at Llangoneyd, and terminates at a bay called Pwll Cawl, at Newton Nottage, in Glamorganshire. From its commencement it is one continual descent, at first 50 feet in a mile, then 15, and afterwards 28 feet.

Ballochney Railway.—The main line is 4 miles in length, with a branch of 1¼ miles, to the village of Clerkston.

Dulais Railway is 8¾ miles in length, commencing at Aber Dulais, and terminating at Cwm Dulais, in the parish of Cadoxtone-juxta-Neath, in Glamorganshire.

Dundee and Newtyle Railway unites these two towns by a line 11 miles in length. The district through which it passes is very hilly, and the height of 544 feet is overcome by stationary engines, and five inclined planes; here coaches and passengers are drawn by locomotives.

Edinburgh and Dalkeith.—The main line is in length 10¾ miles, and the three branches 6½ miles. It commences on the south side of the city of Edinburgh, and terminates near Newbattle Abbey on the banks of the South Eske river.

Garnkirk and Glasgow is 8¼ miles in length; it commences at Cargill Colliery, near Gartsbarrie Bridge, in Lanarkshire, and terminates on the road between Glasgow field and Keppoch. The locomotive engine is here employed for the transport of coals and other articles of commerce.

Heck and Wentbridge is 7½ miles from its commencement at Heckbridge to Wentbridge, in the West Riding of the county of Yorkshire.

Liverpool and Manchester, opened throughout on the 15th of September, 1830, is in length 38 miles 23 chains; its termini are Lime Street, Liverpool, and Hunt's Bank, Manchester. The gauge of its way is 4 feet 8 inches, ruling gradients 1 in 89, rise in feet per mile 59, and its cost per mile 50,923*l*. The total sum expended to June, 1845, was 1,798,506*l*., and the cost of working for six previous months was 65,610*l*.

Canterbury and Whitstable Railway: its total length is about 6¼ miles; there are a number of inclined planes, at far too great an angle to permit the use of locomotives, except on a very small portion of the line, consequently, two stationary engines of 25-horse power, and another of 15 are made use of. Near Canterbury is a tunnel ½ mile in length, 12 feet in width, and the same in height; and the highest elevation of the line is midway, 220 feet above the level of the sea at Whitstable.

Johnstone and Ardrossan Railway is 22⅜ miles in length, it commences at the canal wharf at the first mentioned place, and terminates in the harbour at the latter.

Bristol and Gloucestershire. — This railway is in length 22 miles 10 chains; it commences near the floating dock at Cuckold's Pitt, on the east side of Bristol, and terminates at Gloucester. The gauge of its way is 7 feet, the ruling gradients 1 in 330, and the cost per mile 22,700*l*. It was opened throughout on the 8th of July, 1845.

Bolton and Leigh is a part of the Liverpool and Manchester line; its length is 9 miles.

Bridgend Railway is 4½ miles in length, and in that distance rises 190 feet. It proceeds from Bridgend to the village of Ceffn Gribbwr, in Glamorganshire.

Llanelly Railway, in the county of Glamorgan.

Clarence Railway commences at Samphire Beacon, on the river Tees, and after a course of 15½ miles unites with the Stockton and Darlington railway. There are also six branches, which together extend more than 30 miles.

Warrington and Newton is attached to the Liverpool and Manchester line; its length is 4¼ miles.

Wishaw and Coltness Railway commences at Chapel, and at Old Monkland unites the Monkland and Kirkintilloch railway; it has several branches to the neighbouring collieries.

Leeds and Selby, in length 20 miles, forming a portion of the York and North Midland.

Leicester and Swannington is 15¾ miles in length. At its commencement is a tunnel 1¾ miles in length; it forms a portion of the Midland railway.

Dublin and Kingstown. — This railway is 6 miles and 4 chains in length; at its commencement, the rails are placed at an elevation of 20 feet from the ground, and are carried across the streets of Dublin upon flat arches of an elliptical form. The breadth of this viaduct is 60 feet between the parapets, and contains four lines of rails, which, after passing this arched road, are brought to the level of the ground, and the boundary on each side is marked by a green sod bank, protected by a quickset hedge and a deep ditch.

From Mercon to Blackrock, the road is elevated across the strand at high water, it having the appearance of a long mole stretching across the sea; it passes through a deep cutting among the granite rocks, and along the edge of the cliff. The cost of the work, including the locomotive-engines and carriages, was upwards of 40,000*l*. per mile. The width of the gauge is 4 feet 8½ inches, ruling gradients 1 in 440, and rise in feet per mile 12. The total sum expended to February, 1845, was 359,000*l*.

London and Greenwich was the first railway which started from the metropolis; its length is 3 miles 60 chains; the rails are laid throughout on a viaduct composed of more than a 1000 brick arches, each of 18 feet span, 22 feet in height, and 25 feet in width from side to side. The termini are at London Bridge and Greenwich; the gauge of its way is 4 feet 8½ inches on a level, and it was opened throughout 24th of December, 1838. It cost per mile 266,322*l*., and the total sum expended up to June, 1845, was 986,682*l*.; and the cost of working for the previous six months was 15,384*l*.

Grand Junction Railway is in length 82½ miles, and the whole passes without a tunnel from Birmingham to Newton in Lancashire, where it unites with the Liverpool and Manchester line. Its course is through or near the towns of Walsall, Bilston, Wolverhampton, Penkridge, and Stafford, the Potteries, Nantwich, Middlewich, Northwich, and Warrington. The cost is stated to have been 1,500,000*l*. sterling, or 18,180*l*. per mile; it was opened throughout, 4th of July, 1837. The Birmingham terminus is 371 feet 5 inches above the level of low water at Liverpool, which difference of level is increased in the first 15 miles to 422 feet, giving a rise of 3 feet 6 inches per mile.

From Wolverhampton to Stafford is 15 miles, in which distance there is a fall of 157 feet, or 10 feet 6 inches per mile. From Stafford to the Whitmore station is 14 miles, in which length there is a rise of 116 feet, or about 8 feet per mile. From thence to Warrington is 35 miles, on a descent of 331 feet, or 9 feet 6 inches per mile. The remaining 4¾ miles to Newton is again a rise of 60 feet, or 12 feet 8 inches per mile. The greatest inclination is in the 3 miles between Madeley and Crewe, where it is 1 in 180.

At Vale Royal, about 64 miles from Birmingham, the river Weaver is crossed by a viaduct of stone; there are five arches each 63 feet span, and 60 feet in height, with parapets of 12 feet, making the total height 72 feet above the river; the length of this viaduct is 456 feet. Four miles beyond is the Dutton viaduct, composed also of twenty stone arches, each spanning 60 feet. Where the railway crosses the Mersey and Irwell canal, there is a bridge of stone having twelve arches; the two in the centre are 75 feet span; that which crosses the canal is 40 feet, and the others are 16 feet 6 inches. The gauge of its way is 4 feet 8½ inches; ruling gradients 1 in 177, rise in feet per mile 29. The total sum expended to June, 1845, was 2,597,317*l.*, and the cost of working for the previous six months was 96,336*l.*

The Newcastle and Carlisle: its length is 62 miles. In the first 42¾ miles from the first named place, there is a rise of 10 feet 3 inches in a mile, or 1 in 515; in the next 6 miles there is a fall of 5 inches in a mile; and in the remaining distance, a fall of 390 feet, which is 30 feet in a mile, or 1 in 176. The level at Carlisle is 45 feet higher than at Newcastle. At Middle Gelt Bridge, near Brampton, is a viaduct which crosses two public roads and the river Gelt, at the height of 80 feet above the bed of the river, over which it is carried in an oblique direction, so as to prevent any bend in the inclination of the rails. The arches, which are three in number, are each 33 feet span, and are built at an angle of 45 degrees.

This railway was opened throughout on the 18th of June, 1839; the gauge of its rails is 4 feet 8½ inches, ruling gradients 1 in 106, rise in feet per mile 50, and cost per mile 17,838*l.* The total sum expended to December, 1844, was 1,252,845*l.*, and the cost of working for the previous six months 64,501*l.*

Newcastle and Darlington has its termini at Rainton; it is in length 23 miles, and was opened throughout 18th of June, 1844. The gauge of the way is 4 feet 8½ inches, and the cost per mile 20,000*l.* The total sum expended to June, 1845, was 1,156,378*l.*, and the cost of working for the previous six months 19,138*l.*

London and Birmingham Line was opened for public use throughout its entire length on the 17th of September, 1838. The London terminus is at Euston Square, and occupies 7 acres; a short distance beyond, at Park Street, Camden Town, is a plot of 33 acres of ground covered with buildings of various kinds for the use of the engines, waggons, carriages, and luggage department. These two stations are united by a deep cutting, over which are seven bridges: the distance, which is 1¼ miles, being an inclined plane, the carriages are drawn up it by two stationary engines of 60 horse-power each, by means of an endless rope wound round two cylinders; the trains on their arrival from Birmingham are propelled from Park Street to Euston Square by their own momentum.

The tunnel at Primrose Hill is 1120 yards in length, clear width and height 22 feet; the constructions throughout are of brick; there are five ventilating shafts placed at regular distances. Kensall Green tunnel, 3 miles beyond, is in length 320 yards.

The river Brent is crossed by a viaduct of seven arches, and a little beyond Watford is another tunnel, 1 mile and 70 yards in length, 25 feet high, and 24 feet wide; beyond Leighton Buzzard is another tunnel, 272 yards long.

At Blisworth, about 5 miles from Castle Thorpe, is a cutting 2 miles in length, at an average depth of 50 feet, through blue limestone rock; the quantity removed is said to have been 1,200,000 cube yards. Five miles beyond, where the railroad passes under the Old Watling Street, is Weedon tunnel, 418 yards long. To this succeeds the Kilsby tunnel, 2398 yards in length. At Beechwood, near Hampton-in-Arden, is another tunnel, 300 yards long. According to a statement made by the engineer, Mr. Robert Stephenson, the works were taken by public contract; the company provided blank tenders, to be filled up with schedules of prices, on which an estimate was founded: at the end of every month, the work was measured up, priced according to the list, and the amount paid, with the exception of 20 per cent., which was withheld until the contract was finished according to the tenders.

The stone blocks for the chairs were delivered at 6*s.* each, and the price for the excavation of ordinary materials was from 1*s.* to 1*s.* 6*d.* per yard; the average price of the cutting 13*d.* the highest price paid being 14*d.*, which was clay, sand, and marl, with a lead of 1½ miles only. If the lead was 3 miles, 17*d.* or 2*d.* per mile extra for the leading. Through the rocks in Northamptonshire it was 2*s.* 3*d.* per cube yard. The average lead upon the whole line was 1¼ mile; 1½*d.* per yard was added for stock found by the company, as waggons, rails, &c.

At Chalk Farm the company found all the materials, and paid the contractor 7½*d.* per cube yard, with a lead of about 600 or 800 yards; he afterwards had 8*d.* One shilling and twopence farthing per cube yard is the true cost, after adding interest of money, &c.: this amount does not include the resodding of the slopes, nor any expenses which might arise from slips, &c.

The London clay is as easily worked in fine dry weather as any other material, but in wet weather the labour is exceedingly great. The waggons generally held two cubic

yards, and some dexterity was always required in filling them; if too full, they frequently tilted on the road; the number of boxes in one train varied from 8 to 16, and the locomotive which led them averaged 25 journeys a day, 3 in an hour being the utmost; they worked from 6 to 6, two hours being allowed for rest; the distance run was a mile, which was done with ease in 4 minutes.

Eleven horses were employed to lead the waggons to and fro, from the end of the line, after the engine had left them, a distance of 600 yards. The engine went down a permanent road, but the boxes passed along a temporary one to the end, the rope being attached diagonally, to prevent any waste of power: the Scotch fir sleepers employed cost 3*s.* to 3*s.* 6*d.*, larch sleepers 6*s.* to 6*s.* 6*d.*, oak sleepers at Coventry 7*s.* 6*d.* A mile required 3000 sleepers; thus the saving in a double line, if Scotch fir could be used, would be 1200*l.* per mile, compared with larch it would be 300*l.*, and with oak 600*l.* Oak sleepers, upon a permanent road, will answer as well as stone, and also upon embankments for the first 4 or 5 years, after which it is advisable to replace them with stone.

Fourpence-halfpenny per cube yard was charged for locomotive power. The locomotive was let at $\frac{4}{10}$ of 1*d.* per ton per mile at the Stockton and Darlington Railway, but the fire cost the engine-man from 3*s.* 6*d.* to 4*s.* per ton, while at Willesden it cost 2*s.* 6*d.*; at Liverpool and Manchester $\frac{6}{10}$ of a penny was paid for the loan of the engine.

Embankment at Willesden Green.—The extreme height is 13 feet, the slope 3 to 1; at the end were 6 roadways. The expenses of working on dark nights were nearly double those of the day, in which period from 1000 to 1200 cube yards of earth were generally thrown out. The Birmingham line is 111 miles long, and contains 12,500,000 cube yards of excavation, which on an average may be taken at 14*d.* per cube yard. The price for fencing was 4*s.* per double yard, for tunnelling 30*l.* per yard, ballasting, laying the permanent way, and rails, 4000*l.* per mile.

Mr. Robert Stephenson was paid a salary, and an allowance for travelling expenses, preparing the specifications, and furnishing an estimate. Only 13 miles of the road is perfectly level, the rest is by a series of inclined planes, the least favourable inclination being 1 in 330, or 16 feet in a mile. The whole length is 164 miles 20 chains, which includes a branch to Leamington and Warwick of 9 miles, and another to Northampton and Peterborough of 44 miles. The Birmingham station covers 10 acres of ground, and is about 250 feet above the level of the London. The gauge of the railway is 4 feet 8½ inches; the ruling gradients are 1 in 330; rise 16 feet per mile. Its cost per mile was 52,882*l.*: the total sum expended upon the works to June, 1845, was 6,997,065*l.*, and the cost of working for the six months terminating at that time was 192,915*l.*

Manchester and Birmingham, opened throughout 10th May, 1842, is in length 31 miles; the gauge of its way is 4 feet 2½ inches, ruling gradients 1 in 378, rise in feet per mile 13. Its cost per mile was 61,624*l.*, and the total sum expended to July, 1845, was 2,031,375*l.*, and the cost of working for the previous six months was 34,789*l.*

South-Western or *London and Southampton* was opened for its whole length on May 11th, 1840; its length is 94 miles 10 chains, including the branch to Gosport, of 15 miles 61 chains, and there is no tunnel of any extent. The average earthwork per mile was about 142,000 cubic yards. The gradients nowhere exceed 1 in 250, being rather more than 21 feet per mile, and the gauge of the way is 4 feet 8½ inches.

The report of the company, as made up to June 30th, 1840, was as follows:—

	£	s.	d.
Expenditure in raising the capital and procuring the act	41,467	2	0
Land, compensation, &c.	291,200	2	5
Works of road and station	1,114,605	5	2
Rails, chairs, and sleepers	340,006	0	7
Waggons, tools, and stores	59,566	4	4
Engines and carriages	140,325	16	0
Surveying and engineering	33,448	19	7
Salaries, rent, incidental expenses, &c.	24,729	3	6
Directors' expenses	5,350	0	0
Debentures, bond stamps, brokerage, &c.	3,687	11	10
	£2,054,386	5	5

The cost per mile was 27,874*l.*, and the total sum expended by the company up to June, 1845, was 2,620,724*l.*, and the cost of working for the previous six months 83,055*l.*

Great Western Railway is 205 miles 20 chains in length; the termini are at Paddington, London, and Temple Mead, Bristol. Mr. Brunel was the engineer.

The Box tunnel, between Cheltenham and Bath, is in one part 400 feet below the surface; it is 9680 feet in length, 35 in width, and 39 high. There are 13 shafts, varying in depth from 80 to 306 feet. The quantity excavated was 414,000 cubic yards, and the brickwork and masonry more than 54,000 cubic yards. Thirty millions of bricks were used; a ton

of gunpowder and the same weight of candles were consumed every week for 2½ years, 1100 men and 250 horses being constantly employed.

The rock is freestone, and the water poured in with such violence that, notwithstanding the constant use of the pumps, it filled the tunnel, and rose to a height of 56 feet in the shaft; this difficulty was at length overcome by means of an additional engine of 50-horse-power, discharging 32,000 hogsheads per day.

The inclined plane through this tunnel is 1 in 100; instead of the ordinary rails thin plates of iron are substituted, their inner edges being supported upon a thick felt, which causes the rails to bend under the weight of the passing engines, and retard its progress.

The bridge at Maidenhead, crossing the Thames, has 10 brick arches; the two principal are 128 feet span, the others are from 15 to 25.

The gauge of the way is 7 feet, the ruling gradients 1 in 100, rise in feet per mile 52. It cost per mile 56,372*l.*, and the total sum expended upon the entire work to June, 1845, was 7,717,043*l.*, and the cost of working for the previous six months was 158,367*l.*

The cost to the 30th June, 1841, when the railroad was opened, was thus stated:—

	£	s.	d.
Expenses before the act	89,197	11	3
Land and compensation	720,523	16	3
Works	3,427,429	12	3
Permanent way, timber rails, &c.	926,052	9	11
Premises in Princes Street, Bank	19,600	4	5
Engines and carriages	386,900	8	4
Engineering, surveying, &c. &c.	139,859	3	0
Land valuers, &c.	16,528	10	10
Law charges, conveyancing, &c.	55,815	9	6
Parliamentary expenses	29,104	5	4
Stamps for debentures	10,357	6	0
Office expenses, direction, salaries, &c.	55,751	10	0
	£5,877,120	7	8

Preston and Wyre Railway, for the purpose of connecting the town of Preston with the mouth of the river Wyre, is 19½ miles in length, was opened on the 16th of July, 1840. The gradients nowhere exceed 7 or 8 feet per mile. The gauge of the way is 4 feet 8½ inches, the ruling gradients are 1 in 264, rise in feet per mile 20, and the cost per mile 22,261*l.* The total sum expended to February, 1845, was 490,030*l.*, and the cost of working for the previous six months 7,581*l.*

North Union has its termini at Preston and Peak Side station, on the Liverpool and Manchester railway; its length is 46 miles 30 chains, and was opened throughout the 31st October, 1838. The gauge of its way is 7 feet 8½ inches, its ruling gradients 1 in 100, its rise in feet per mile 52, and its cost per mile 27,326*l.* The total sum expended to June, 1845, was 1,060,550*l.*, and the cost of working for the previous six months 27,010*l.*

London and Croydon Railway was opened on the 1st of June, 1839, the whole distance between the two termini being 10½ miles. This railway may be said to commence where it unites with the London and Greenwich, at Corbett's Lane, although it has an independent station at the London terminus. The distance from the station to Corbett's Lane is 1 mile 60 chains, and the rails branch off in a curve of 90 chains radius; the railway then proceeds along an embankment, 20 feet in height, to New Cross, where it enters a deep cutting; at New Cross is a station, occupying three acres of ground, where there are numerous offices, stationary pumping engines, workshops, and sheds for the carriages, and locomotives. The high Dover road here crosses the railway by a bridge of one arch, 30 feet span, and a height to the crown of the arch of 14 feet 6 inches.

The railway from this station rises up an inclined plane for the length of 2 miles and 50 chains, and during its course passes under six brick bridges; the cutting is in some places 60 and 80 feet in depth. After arriving at the Dartmouth Arms station, the line is nearly level, the greatest deviation from the horizontal being 1 in 660.

The Croydon station occupies an area of seven acres, and contains offices, waiting-rooms, sheds, &c. The gauge of its rails is 4 feet 8½ inches; ruling gradients 1 in 100; rise in feet per mile 52 feet. The cost per mile was 80,400*l.*, and the total sum expended to July, 1845, was 842,592*l.*, and the cost of working for the previous six months was 18,722*l.*

Brandling Junction connects Gateshead with South Shields, in Durham; it was opened to the public the 5th of September, 1839; this railway now forms part of the property of the Newcastle and Darlington Junction railway.

Hull and Selby Railway is 31 miles in length, and commences at the Humber dock, and crossing the Ouse by an iron bridge joins the Leeds and Selby line, on the east side of the Doncaster road; this line is said to be the most level of any hitherto executed, and was opened throughout on the 1st of July, 1840.

There are iron bridges over the Derwent, at Wreple, and the Ouse, at Selby. The greater part of the line is laid with longitudinal timbers and cross sleepers. Messrs. Walker and Burgess were the engineers. The gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 240, rise in feet per mile 22, and cost per mile 22,290*l.* The total sum expended to June, 1845, was 702,173*l.*, and the cost of working for the previous six months 20,587*l.*

Bristol and Exeter Railway is 76¼ miles in length, and chiefly through a level country; its termini are at the stations of the Great Western at Bristol and at the depôt Exeter; it was opened throughout on the 1st of May, 1844: the gauge of its way was 7 feet, ruling gradients 1 in 227, rise in feet per mile 41, and the cost per mile 23,676*l.* The sum expended to June, 1845, was 2,136,546*l.*

Midland Counties Railway is in length 57 miles, including the branch to Derby, of 9 miles. The amount of the earth-work on this line averaged 110,000 cubic yards per mile. There are two short tunnels near Leicester and Redhill; beyond the latter, over the Trent, is an iron bridge of three arches, each spanning 100 feet. Where this railway unites with the Birmingham, at Rugby, is an extensive viaduct. The cost of work to the opening of the line was 1,287,087*l.* 5*s.* 11*d.*; and the total sum expended up to June, 1844, 1,742,729*l.*; and the cost of working for the previous six months, 40,830*l.* The acting engineer was Mr. Woodhouse, the consulting engineer Mr. Vignoles. The gauge of its rail is 4 feet 8½ inches, ruling gradients 1 in 330, rise in feet per mile 16.

Birmingham and Derby Junction Line is 38¾ miles in length; it was opened throughout its whole length on the 12th of August, 1839. After leaving the Hampton station, there is a mile of deep cutting, and then a lofty embankment; the river Blythe is then crossed several times. Between Kingsbury and Tamworth, over the Anker, is a viaduct of eighteen arches, each of 30 feet span, and one oblique arch, of 60 feet span; its elevation above the river is 23 feet, and the cost was 18,000*l.* Before entering Tamworth is a lofty embankment, rising 30 feet, and midway between Tamworth and Burton-on-Trent is a viaduct, ¼ mile in length, built upon a thousand piles, driven 15 feet below the bed of the river. The gauge of its way is 4 feet 9 inches, ruling gradients 1 in 339, rise in feet per mile 15, and cost per mile 24,633*l.* The total sum expended to June, 1844, was 1,212,645*l.*, and the cost of working for the previous six months, 23,563*l.*

An act was passed in 1844 for consolidating the Midland Counties, North Midland, and Birmingham and Derby railways; the total sums expended upon which amounted to the 30th of June, 1845, to 6,327,690*l.* 16*s.* 8*d.*

Manchester and Leeds Railway is in length 56 miles 40 chains, whilst the distance between the termini in a straight line is only 35 miles; Mr. George Stephenson was the engineer. At Littleborough, near Rochdale, is a tunnel nearly 1¾ miles in length, lined with brick. The summit tunnel at Littleborough, 2869 yards in length, 21 feet 6 inches in height from the level of the rails, besides a depth of about 6 feet from the rails to the centre of the invert; the width at the level of the rails is 22 feet, and the widest part 24 feet. There are fourteen air-shafts, averaging in depth 177 feet; and in order to complete this portion of the work, besides the 1000 men usually employed, there were thirteen steam-engines, in united power equal to 100 horses. The average rate of progress was about 127 yards of length each month; 23,000,000 bricks were used in lining the tunnel, and 8000 tons of Roman cement; its inclination is towards Manchester, and at one point it is 400 feet below the surface. In the centre is a large culvert or drain to carry off the water, covered with flag-stones. The rails are supported at short intervals, the sleepers being placed only 2 feet 6 inches apart. The total cost was 251,000*l.* At Charlestown is another tunnel 250 yards in length. At Horbury is a deep rock cutting of nearly 70 feet, and at Sowerby Bridge another of 80 feet.

In September, 1841, the items of expenses were thus stated:—

	£	s.	d.
Parliamentary expenses	48,500	5	9
Engineering ditto	40,359	3	7
Land and compensation, &c.	295,935	14	9
Works, including permanent way	1,821,015	3	5
Stations	168,562	15	2
Directions and travelling expenses	12,602	18	2
Office expenses, salaries, advertising, &c.	6,827	19	1
Stamps and interest on loans	88,841	16	10
Law charges	10,266	18	3
Locomotive-engines, carriages	152,586	0	6
On account of branches	83,771	6	4
	£ 2,728,270	1	10

This railway was opened throughout on the 1st of March, 1841. The gauge of its rail

is 4 feet 8½ inches, ruling gradients 1 in 150, rise in feet per mile 35, and cost per mile 46,968*l.* The total sum expended to June, 1845, was 3,372,240*l.*, and the cost of working for the previous six months 92,934*l.*

Sheffield and Manchester, opened throughout 14th of July, 1845, is 40 miles 66 chains in length; the gauge of way is 4 feet 8½ inches, ruling gradients 1 in 220, rise in feet per mile 44, and the total sum expended to June, 1845, was 1,249,932*l.*

Manchester, Bolton, and Bury, opened the 29th of May, 1838, is in length 10 miles; the gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 160, rise in feet per mile 33, and cost per mile 67,000*l.* The total sum expended to June, 1845, was 813,980*l.*, and the cost of working for the previous six months 9772*l.*

Newcastle and Shields Railway is 6½ miles in length, and was opened on the 18th of June, 1839; it commences at the back of Pilgrim Street, Newcastle, and ends at Little Bedford Street, North Shields. The line commences with an embankment, and then passes under the Shields road by a tunnel 70 yards in length; there are altogether twenty-four bridges; one over the Ouseburn has nine arches, two of which at the ends are of stone, the others are of timber resting on stone piers. These wooden arches are formed in eleven thicknesses of Dantzic 3-inch deals bent over each other; between each is a layer of felt dipped in tar, the whole being held together by oak trenails and iron bolts. Each of the five arches consists of three ribs lying parallel to each other, on which are transverse timbers that carry the road. The three centre arches have each a span of 116 feet, and the others 110 feet; the total length of this viaduct is 750 feet, and its height above the water 180 feet. The viaduct at Willingdon Dean has seven timber arches, five of which span 120 feet each, and the two exterior each 115 feet; the whole length is 1050 feet, and the height to the top of the rails 82 feet. These two viaducts cost 26,000*l.* The gauge of the way is 4 feet 8½ inches, ruling gradients 1 in 180, rise in feet per mile 29, and cost per mile 44,233*l.* The total sum expended to December, 1844, was 290,730*l.*

Aylesbury Railway is a straight line of 7½ miles, and branches off from the London and Birmingham line at Chiddington, 35 miles from London; it was opened throughout, the 10th of June, 1839; its gauge is 4 feet 8½ inches, ruling gradients 1 in 118, rise in feet per mile 44, and cost per mile 7500*l.* The total sum expended to February, 1845, was 60,081*l.*

Yarmouth and Norwich, opened throughout the 1st of May, 1845, is in length 20½ miles; the gauge of its way is 4 feet 8½ inches, and is nearly on a level. It cost per mile 11,578*l.*, and the total sum expended to June, 1845, was 259,040*l.*

Arbroath and Forfar was opened on January 3, 1839. Its length is 15¼ miles, and extends from the harbour at Arbroath, where it joins the railway from Dundee to Forfar, in the vale of Strathmore. Its guage is 4 feet 8½ inches, ruling gradients 1 in 130, rise in feet per mile 40, and cost per mile 9213*l.*; the total sum expended to May, 1844, was 135,416*l.*

Dundee and Arbroath, opened July 8, 1840, is 16 miles 50 chains in length; its guage is 4 feet 8½ inches, and nearly level throughout. It cost per mile 8570*l.*, and the total sum expended to June, 1844, was 153,416*l.*

Ulster Railway was opened in August, 1839.

York and North Midland was opened on June 30, 1840; its length is 71 miles 10 chains; the gauge of its way is 4 feet 8½ inches, the ruling gradients 1 in 484, and rise in feet per mile 10; Mr. George Stephenson was the engineer. The cost per mile was 23,900*l.*, and the total sum expended to June, 1845, was 1,279,950*l.*

This railway commences in the city of York, and passes through the city wall by an arch of 70 feet span, which affords room for four lines of rails. After crossing several skew-bridges, and a bridge 274 feet in length over the river Wharfe, which has one arch of 60 feet, and eight of 15 feet span, the main line passes under the Leeds and Selby line near Sherburn, and over the river Aire by a brick bridge, with piers of stone from Bramley Fall; the arches are 65 feet 6 inches span, and built at an angle of 60 degrees; its total length is 313 feet, and its width between the parapet 30 feet.

The Methley branch crosses the Calder by a similar bridge of 3 arches, each spanning 50 feet, and built at an angle of 75 degrees.

Lancaster and Preston Junction, (Mr. Locke, engineer,) is a little more than 20 miles in length; it was opened June 30, 1840. The gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 500, rise in feet per mile 10, and cost per mile 20,192*l.* The total sum expended to June, 1845, was 462,467*l.*

North Midland Railway; its length is 72 miles 29 chains; it was executed under the direction of Messrs. George and Robert Stevenson, and Mr. F. Swanwick, engineer. This railway commences at Derby, where the station covers an area of 26 acres, and has very capacious sheds, offices, workshops, &c. The principal carriage-shed is 450 feet in length, and 140 feet in width, covering 9 separate tracks; one portion extends upwards of 1000 feet, and is 42 feet in width.

The Melford tunnel is 836 yards in length, that at Claycross 1 mile, that at Chevet 600 yards. At Bule Bridge, where the river Amber is crossed, is a viaduct, and the turnpike

road, the railway, and the Cromford Canal, intersect each other at three different levels. There are numerous bridges; two over the Derwent are constructed of timber, one 400, the other 450 feet in length, containing together 200,000 cubic feet of Baltic timber.

The steepest inclination on this line is a slope of 1 in 264, or 20 feet per mile; this occurs for 2½ miles near Wakefield. The gauge of the way is 4 feet 8½ inches, ruling gradients 1 in 330, rise in feet per mile 16. The total sum expended to June, 1844, was 3,346,138*l.*, and the cost of working for the previous six months 56,626*l.* It was opened throughout on June 30; 1840.

Chester and Birkenhead is 14½ miles in length, and the gradients are about 16 feet in a mile. Mr. Stephenson was the engineer, and Mr. Dixon the sub-engineer; its termini are at Monk's Ferry, opposite Liverpool, and at Brook Street, Chester; it was opened throughout September 22, 1840. The gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 330, rise in feet per mile 13, and cost per mile 34,198*l.* The total sum expended to June, 1845, was 511,046*l.*, and the cost of working for the previous six months 8188*l.*

Chester and Crewe was opened October 1, 1840, Mr. Stephenson being engineer. This railway commences at Brook Street, Chester, and unites with the Grand Junction Railway at Crewe, about 53 miles from Birmingham. An aqueduct conveys the Ellesmere Canal over the line at Christleton, and over the Weaver is an extensive viaduct. This railway now forms a portion of the Grand Junction.

Stockton and Hartlepool railway, 8 miles in length, was opened in December, 1840. Messrs. Leather and Sons were the engineers. At Greatham Meadows is a viaduct, 700 yards in length, and 30 feet high, of 92 brick arches, and an embankment along the seashore for ¾ mile, the sides of which are formed of clay puddling in a curvilinear form, which allows the sea to fall easily upon it.

Northern and Eastern terminates at its junction with the Eastern Counties, 3 miles from Shoreditch, and at Ely it unites with the Norfolk railway; its length is 70 miles 10 chains, and was opened in July, 1845; its gauge is 4 feet 8½ inches, ruling gradients 1 in 330, rise in feet per mile 16; total expended 1,122,498*l.*, or per mile 31,256*l.*

Eastern Counties terminates at Shoreditch, London, and at Colchester; its length is 151 miles 10 chains; it was opened throughout March 20, 1843; its gauge is 4 feet 8½ inches, and its ruling gradients 1 in 100, rise in feet per mile 52. The total sum expended to July 4, 1845, was 2,954,755*l.*, or 46,355*l.* per mile, and the cost of working for the previous six months 92,974*l.*

Glasgow, Paisley, Kilmarnock, and Ayr, (Mr. Miller, engineer,) was partly opened September 19, 1840; its length is 40 miles. There are a number of bridges on the joint line, and an extensive viaduct at Paisley. Over the Cart is a stone bridge of one arch, 85 feet span, and at Tradeston the line crosses the Polloc and Govan railway by a bridge. At Arkleston is a short tunnel, and another at Two-mile House.

From Glasgow to Paisley the distance is nearly 7 miles, and from Paisley to Ayr 33½ miles. At Bishopton is a considerable cutting, and a tunnel through the solid whinstone rock.

The gauge is 4 feet 8½ inches, the ruling gradients 1 in 440, rise in feet per mile 12, and cost per mile 20,607*l.* The total sum expended to January, 1845, was 1,071,257*l.*, and the cost of working for the previous six months 21,706*l.*

Edinburgh and Glasgow, opened throughout February 18, 1842, is in length 46 miles. Its gauge is 4 feet 8½ inches, ruling gradients 1 in 880, rise in feet per mile 12, and cost per mile 35,024*l.* The total sum expended to January, 1845, was 1,686,556*l.*, and the cost for working for the previous six months 30,783*l.*

Taff Vale Railway, (Mr. I. K. Brunel, engineer, with Mr. Bush,) was opened on October 8, 1840; its length is about 24½ miles; it extends from the port of Cardiff to Merthyr Tydvil, and cost per mile 25,000*l.* This line has but one track, and is worked by locomotives, except at Navigation House, where there is an inclined plane, and a stationary engine of 50-horse power. The inclined plane is ½ mile in length, and rises generally 1 in 20, but near the top 1 in 18. There are two short tunnels; the principal one was blasted through the rock, and is 250 yards in length. Near Quaker's Yard is a viaduct, which crosses the Taff, the length of which is 600 feet, and the height above the river 100; it has six arches. Some of the bridges are large; one has an arch of 100 feet span, and 60 feet in height; this crosses the Rhondda at its confluence with the Taaf.

Glasgow, Paisley, and Greenock, (Messrs. Locke and Errington engineers,) opened throughout on the 24th of March, 1841, is in length 22 miles 22 chains, and passes for 2300 yards through a hard whinstone rock, in blasting which 314 tons of gunpowder were used. There are two tunnels, one of 320, the other of 340 yards long, between which is an open cutting, of 70 feet in depth. A thousand men, three steam-engines, and a number of horses, were constantly employed in this work. Gauge of way 4 feet 8½ inches; ruling gradients 1 in 330, rise in feet per mile 16, and cost per mile 35,015*l.* Total sum expended to January, 1845, was 797,643*l.*, and the cost of working for the previous six months 16,680*l.*

Blackwall Line.—Messrs. George Stephenson and G. P. Bidder were the engineers. The

length of the entire line is 8 miles and 1230 yards; its termini are in Fenchurch Street, London, and Blackwall. It crosses the Minories by trussed cast-iron girders, which have a clear space of 63 feet in width, and 18 feet in height: each of these six girders weighs 15 tons. Over Vine Street is a similar construction, 30 feet in span. The greater part of the line runs upon brick arches, about 18 feet above the level of the streets, one of which, crossing Crutched Friars, is oblique, and spans 53 feet 6 inches.

At the London terminus is a long platform, the first portion of which has an inclination of 1 in 100, and the remainder to the Minories, 1 in 240. On this slope, notwithstanding the curvature of the line, the trains descend by gravity. Wire ropes are used, worked by powerful steam-engines, stationed at each end of the line, and turning a barrel, to which a rope of about 6½ miles long is attached. An electric telegraph gives the signal when the engines are to be put in motion, and the train is drawn forward, unwinding the rope at the other cylinder as it proceeds; carriages are stopped at any intermediate station, by means of a brake, after being detached from the rope, while the rest of the train proceeds. When the carriages are prepared for returning, they are again attached to the rope, and are drawn simultaneously by the engines. There are two lines of railway, one used for travelling in each direction. The gauge of its way is 5 feet, ruling gradients 1 in 106, rise in feet per mile 50, and was finally opened on the 2nd of August, 1841. The cost per mile was 288,177*l.*, and the total sum expended to June, 1845, was 1,083,951*l.*, and the cost of working for the previous six months 24,494*l.*

Slamannan Railway was opened in August, 1840; it was a communication between Ballochney and the adjoining railways and the Union Canal at Causeway End, near Linlithgow.

Maryport and Carlisle Railway, open throughout in January, 1845, is in length 28 miles 3 chains; the gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 209, rise in feet per mile 25, and cost per mile 11,500*l.* The total sum expended to June, 1845, was 345,720*l.*, and the cost of working for the previous six months 5,390*l.*

Birmingham and Gloucester.—Captain W. S. Moorsom, engineer. The total length is 55 miles 73 chains, and was opened throughout on the 17th of December, 1840. Its termini are at the Spa Road, Gloucester, and Camp Hill, Birmingham. The gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 37, rise in feet per mile 142, and its cost per mile 26,934*l.* The total sum expended to December, 1844, was 1,527,267*l.*; and the cost of working for the previous six months 44,739*l.*

London and Brighton Railway.—Mr. Rastrick, engineer. The total length of the main line is 41¼ miles; the distance run over the Greenwich and Croydon lines 9¼ miles, making 50¾ miles. This railway, from its junction with the Croydon line, rises for 8 miles about 20 feet per mile, or 1 in 264. At Merstham is a tunnel 1780 yards long, after which the line falls, at the rate of 1 in 264, for the distance of 7 miles. From this point at the Horley station, it rises for about 6¼ miles, and passes through Balcombe tunnel, 1122 yards long. It then falls for another 8½ miles, and rises for 5½ miles, where is the Clayton tunnel, through chalk, 1¼ miles long, from whence there is another fall to the terminus at Brighton.

Across the valley of the Ouse is an aqueduct, 1437 feet in length, and the height varies from 40 to 96 feet; it is formed of thirty-seven brick arches, of 30 feet span. The other tunnels at Patcham and Hayward Heath are 480 and 230 yards long. The rails are laid to a gauge of 4 feet 8½ inches, and are supported by wooden sleepers. The expenditure to the 30th of June, 1841, was thus stated:—

	£	s.	d.
Parliamentary expenses (which does not include the contest)	3,780	10	11
Land and compensation	386,725	7	9
Law, and surveying charges thereon	16,185	11	10
Engineering and surveying	31,030	15	0
Works	1,159,328	9	2
Stations	42,523	4	8
London joint station on account	25,754	2	1
Rails, chains, sleepers	176,872	3	4
Engines and carriages	45,438	13	9
Direction	8,400	0	0
Law expenses	15,969	3	11
Office expenses, salaries, &c.	31,023	11	0
Interest, stamps, commission on mortgage bonds	7,975	3	11
	£ 1,951,906	17	4

The assent was given to the bill for the formation of this railroad on the 15th of July, 1837, and it was finally opened to the public on the 21st of September, 1841. The total sum expended to June, 1845, was 2,659,672*l.*, and the cost of working for the previous six months, 66,933*l.*

South-Eastern Railway.—Its termini are near London Bridge and Dover; its length is 88 miles 10 chains; the gauge of its way is 4 feet 8½ inches; the ruling gradients 1 in 264, and the rise 20 feet per mile. It was opened throughout on the 6th of February, 1844. The total sum expended up to July, 1845, was 4,306,478*l.*, and the cost for the previous six months was 123,462*l.* Assent was given to the bill on the 21st of June, 1836.

Ulster Railway, in length 36 miles, has its termini at Belfast and Armagh; its gauge is 5 feet 6 inches.

Dublin and Drogheda, in length 37 miles, was opened throughout the 26th of May, 1844; its gauge is 5 feet 3 inches, and it cost per mile 16,533*l.* The total sum expended to December, 1844, was 579,253*l.*

Great North of England Railway, (Mr. Robert Stephenson engineer,) has its termini at Darlington and at York; its length is 45 miles 19 chains, and was opened throughout in 1842. The gauge of its way is 4 feet 8½ inches, ruling gradients 1 in 330, rise in feet per mile 16, and the cost per mile 26,855*l.* The total sum expended to June, 1845, was 1,296,200*l.*, and the cost of working for the previous six months 31,031*l.*

Railways.	Length.		Total Sum expended.	Cost of working for Six Months.	Returns for the same Time.
	Miles.	Chains.	£	£	£
Great Western	205	20	7,717,043	158,367	433,296
London and Birmingham	164	20	6,997,065	192,915	452,881
South Eastern	88	10	4,306,478	123,462	160,402
Manchester and Leeds	56	40	3,372,240	92,934	153,279
North Midland	72	29	3,346,138	56,626	112,866
Eastern Counties	51	10	2,954,755	92,974	114,807
London and Brighton	30	20	2,653,672	66,933	109,831
South Western	94	10	2,620,724	83,055	169,789
Grand Junction	82	50	2,597,317	96,336	226,326
Bristol and Exeter	76	10	2,136,546	44,951	
Manchester and Birmingham	31	0	2,031,375	34,789	72,540
Liverpool and Manchester	38	23	1,798,506	65,610	134,124
Midland Counties	47	36	1,742,729	40,830	68,153
Edinburgh and Glasgow	46	0	1,686,556	30,783	61,047
Birmingham and Gloucester	53	30	1,527,267	44,739	70,096
Great North of England	45	19	1,296,200	31,031	59,899
York and North Midland	71	10	1,279,950	28,484	77,791
Newcastle and Carlisle	61	67	1,252,845	64,501	78,484
Birmingham and Derby	38	68	1,212,645	23,563	36,063
Sheffield and Manchester	40	66	1,249,932	9,629	18,746
Newcastle and Darlington	23	0	1,156,378	19,138	70,276
Northern and Eastern	79	10	1,122,498	19,647	45,759
London and Blackwall	3	38	1,083,951	24,494	29,525
Glasgow, Paisley, Kilmarnock, and Ayr	40	0	1,071,257	21,706	42,720
North Union	46	30	1,060,550	27,010	51,404
London and Greenwich	3	60	986,682	15,384	18,058
London and Croydon	10	26	842,592	18,722	36,027
Manchester, Bolton, and Bury	10	0	813,980	9,772	25,038
Glasgow, Paisley, and Greenock	22	22	797,643	16,680	23,447
Hull and Selby	30	51	702,173	20,587	35,054
Bristol and Gloucester	22	10	667,822	19,685	27,544
Taff Vale	24	40	623,102	18,543	24,894
Dublin and Drogheda	32	0	579,253	13,313	21,572
Chester and Birkenhead	14	72	511,046	8,188	15,570
Preston and Wyre	19	60	490,030	7,581	13,537
Lancaster and Preston	20	18	462,467	- -	13,832
Stockton and Darlington	25	30	450,000		
Dublin and Kingston	6	4	359,000	29,263	53,740
Ulster	36	0	358,353	5,190	14,743
Maryport and Carlisle	28	8	345,720	5,390	8,406
Durham and Sunderland	13	20	301,248	11,334	17,347
Yarmouth and Norwich	20	40	259,040	5,289	7,286
Newcastle and North Shields	6	79	290,730	15,022	19,152
Dundee and Arbroath	16	50	153,416	8,633	13,987
Arbroath and Forfar	15	15	135,416		

In the preceding table is shown the length, total sum expended, cost of working for six months, and the returns for the same time upon forty-five of the principal railroads completed; and as the works upon them were mostly of a similar kind, it was deemed advisable to reserve the descriptions which relate to the detail to that portion of the volume devoted to theory and practice. The various locomotive-engines, the different forms of the rails, and the machinery, is described under the separate heads of machines and their movers. For the construction of these railways the civil engineer and architect have contributed their labours; for the machines and engines afterwards applied to it, we are indebted to the several manufacturers now established throughout England. By the united labours of the civil and mechanical engineers a new era has opened upon us, which eventually will lead to the most beneficial results.

Atmospheric Railway.—Dr. Papin exercised his skill in attempts to derive mechanical power from the motion of a piston in a cylinder, and thus produce a vacuum. He first made his experiments with gunpowder, and afterwards with steam; he placed a cylinder containing a little water and a piston over a small fire; as soon as steam was created the piston of course rose, and after the fire was taken from under it the steam cooled down, and the piston again descended. Papin, however, applied his discovery, if it might be so termed, only to mere models; he made no attempt to gain a succession of strokes for his piston, nor to produce rapidity of motion; he thought it might be so worked, but did not point out any method by which it could be performed.

Mr. Valence in the year 1824 was the first to impel a piston through a tunnel, which he did at Brighton, and immediately afterwards took out a patent to secure his invention. This was to be applied to the transmission of railway carriages, and the plan consisted of a series of cylinders of large diameters, within which they were to pass with passengers or goods, being propelled by the pressure of the air upon a disc which was placed in front of the first carriage: the cylinders were exhausted by air-pumps placed at their ends; the atmosphere then pressing with all its power against the disc, pushed it forwards in the vacuum already produced by the air-pumps.

Mr. Medhurst in 1827 endeavoured to carry out a project he had described sixteen or seventeen years before, as a method of rapidly conveying goods and passengers through a tube of 30 feet diameter, by the power and velocity of the air.

Mr. Pinkus in 1834 took out a patent for an extended cylinder or main 40 inches in diameter, with a longitudinal opening along the upper side, through which an arm extended from the piston to the leading carriage, which, with the rest of the train, ran upon the rails on the outside of the main. The aperture of the cylinders in advance of the pistons was closed air-tight, by a flexible cord which was raised by a grooved wheel in the centre of the carriage, and pressed down by two other wheels at the ends as the train advanced. In front of the piston a partial vacuum was produced by means of air-pumps, and the atmosphere was supposed to rush into the cylinder through the groove, which was laid open by the raising of the cord.

Mr. Samuel Clegg, who had been engaged in making some of the arrangements to carry out Mr. Pinkus's invention at Wormwood Scrubbs, and to demonstrate the principles of the pneumatic railway, discovered that the vacuum might be improved, and in conjunction with Mr. Samuda took out a fresh patent. It is now proposed that the moving power shall be through a continuous pipe laid between the rails, and divided by separating valves into convenient lengths for the purpose of exhaustion. A partial vacuum is formed in this pipe by air-pumps, which are worked by steam-engines placed at various distances; the separating valves are opened as the train progresses. At the top of the pipe or main is a continuous groove covered with a valve, made of stout leather riveted between two iron plates, that at the top being wider than the other, to allow of the valve closing and effectually covering the groove; when the valve falls the edge lies upon a composition of bees-wax and tallow, which is passed over by a heater made fast to the frame of the leading carriage. The pipe is exhausted in front of the piston, which is attached to the carriage by a connecting plate, serving to draw the train as well as to sustain the piston when in motion. This plate has also attached to it a frame on four wheels, which lifts and sustains the continuous valve, whilst the plate is in motion along it; this is kept open beyond the plate by means of the two outer wheels, and the atmosphere is thus admitted behind the piston. The main or pipe is of iron cast in 9 feet lengths, and put together with socket joints, caulked carefully with yarn and a cement made of whiting, boiled linseed oil, olive oil, or any other, the drying qualities of which are not rapid; tallow is afterwards used and tarred yarn, to make the joint perfect; the whole is in a soft state, and is not affected by either the contraction or expansion of the metal. The heater, which is described as passing over the valve, consists of a trough filled with charcoal, and at the bottom is a copper blade, which rests on the surface of the composition, and being always hot slightly melts it; thus by closing it, the joint is rendered again air-tight as the train passes along. The entire main is separated into lengths of 3 miles each, by valves which open in a direction to suit the passage of the trains; these valves act in a semi-

circular valve-box placed underneath the pipe; the valve is opened by the wheel of the first carriage depressing a lever on the outside of the pipe, which disengages a catch that occasions a weight to move a slide valve across two openings of the valve-box on either side. In one position of the valve the air in the chamber finds its way into the exhausted tube; and on the other, the valve which is attached to the same fulcrum as the first is opened by the external pressure; this is a very ingenious part of the contrivance. The disc in the inclined position is a little larger than that in the pipe, and thus keeps it closed until the slide is moved. To the fulcrum of this valve is attached the weight, by which the action of the wheel is disengaged; there are two sets of these valves, to allow of a transit in either direction.

When the first steam-engine is worked, a vacuum is made in the first length of the pipe; the piston is then introduced, and the valve opened; when the train begins to move a signal is given by means of an electric telegraph, and the second engine is set to work, so that when the first length of pipe is passed through, the second is exhausted, and after passing the branch connected with the first pump, the exit valve of the first division is opened, as well as that of the second, and the train passes on without any interruption whatever; the third engine then does its work in a similar manner, and so on. When $\frac{2}{3}$ of a vacuum are produced before the train enters the section of pipe it is to pass over, it is propelled by nearly twice the power required to work the air-pump during its motion; for the mean pressure on the piston of the air-pump, working at this degree of vacuum, is only $5\frac{1}{2}$ pounds per inch, whilst that on the piston in motion is 10 pounds.

Experiments were made on the Dalkey railroad, upon the amount of leakage of the main there laid down, which was 15 inches in diameter; the total contents of this main or pipe were estimated as containing 10,680 cubic feet, and in the space of 41 seconds it was not found more than 356 cubic feet, an inch of mercury being all the reduction which took place in the vacuum; this leakage has been estimated as equal to 10 horse-power per mile, or 30 horse-power for each section of 3 miles.

The Electric Telegraph, adopted on some of the lines of railroads, is remarkable for the great ingenuity displayed in applying electricity to communicate intelligence from one point to another; telegraphs so set in motion were the invention of Messrs. Cooke and Wheatstone.

When the required communication is to be made, the operator upon the machine commences by sounding a bell, which he does by a very simple apparatus. In connection with the instrument are two coils of wire, the ends of which, passing through the bottom of the frame, are attached to the general wires of communication; a piece of soft iron is fastened to a lever, which is firmly held against a pin. The electric current attracts the iron by magnetic influence, releases the pin, and, giving motion to the wheels of the machine, produces a loud and clear ringing, which is attended to at the station where the information is to be conveyed. The communication is then made by letters, every word being spelt, each letter having the distinct motion of a pointer or index applied to it, which works on a dial divided into five circles, each containing a number of letters, all indicated by needles. The left-hand needle moved twice gives A, three times B; once to the right and once to the left, C; once to the left and once to the right, D; once to the right E, twice F, three times G. The order is then taken up by the right-hand needle moving once to the left for H, twice for I, three times for K, once to the right and once to the left for L, once to the left and once to the right for M, once to the right for N, twice for O; and three times for P. The remaining signs are made by the two needles conjointly, so that the simultaneous movement of the two once to the left indicates R, twice for S, three times for T, once to the right and once to the left for U, once to the right for W, twice for X, and three times for Y. At the end of each word the left hand needle moving once to the right to the cross, indicates the word is complete, and when the receiver understands it, he moves the same pointer twice to the left and twice to the right, which indicates *yes*. When not understood, the needle E is pointed twice to the right and twice to the left, which indicates *no*, and then the original word is repeated. Doubling the motions for each letter, figures are obtained.

The signals are given by two magnetic needles or pointers, each suspended vertically on its axis, passed through the dial; behind the dial is fixed another pointer on each corresponding axis. A portion of the conducting wire, many yards in length, is coiled round the galvanometer frame, in which the magnet moves, so as to subject the magnet to the multiplied deflecting force of the electric current; the motion of the pointers is limited by a fixed stop or pin at either side.

When a communication is to be made, the conductor turns the handle to the right or left, so as to break the electric circuit, and press the wire against pins connected with the battery poles; the coils of wire thus receiving the full deflective force attract the magnetic needles to either side, according to the course of the current; thus, if the stream of electricity first passes into the coil, the upper part of the needle will be attracted to the left, thus giving the whole motion necessary to the pointers. The movement of the handles, and consequent deflection of the pointers at either end of the line, are simultaneous, and

there is no time lost between the sending and the receipt of the intelligence. To convey the wires from one station to another, posts 16 or 17 feet high are fixed in the ground at every 400 or 500 yards, which support them in the air. Three wires on the lines, one apparatus and one set of wires at each station, are all that is required to complete the machine.

The battery at each station is about 2 feet in length, and 6 inches in width: if the wires connected with it were kept continually attached to the signal wires, they would produce constant motion at the other end; to obviate this another wire conducts the electricity into the earth when the telegraph is not at work, and an attendant is always present at each dial; when a signal is made, he attaches the wire again to the battery. The wires are all copper and coated with zinc.

Gas Lighting.—About the year 1739, there is a notice in the Philosophical Transactions of the discovery of coal-gas by the Rev. John Clayton, Dean of Kildare; this gas, called "the spirit of coal," was obtained from a retort placed in an open fire, and Dr. Clayton observes, that "at first there comes over only film, afterwards a black oil, and then a spirit arose which could not be condensed, and it broke the lute as well as the glasses. This spirit caught fire at the flame of a candle, and continued burning with violence as it issued out in a stream; a quantity was collected in bladders, and a hole being made, the gas as it issued was lighted, and allowed to burn out for the amusement of his friends."

In the year 1767, Dr. Richard Watson, afterwards Bishop of Llandaff, made some experiments upon the distillation of pit coal; he allowed the gas to mount by curved tubes, and describes, in the second volume of his chemical essays, its great inflammability as well as elasticity; he also found that it retained the former property after it had passed through a great quantity of water.

These discoveries do not appear to have been applied to the purpose of lighting until some years afterwards: in the streets of the metropolis, as well as those of most of the provincial towns of importance, oil lamps were used, though very inadequate to their purpose, and it is difficult to say how or by whom coal gas was first introduced as an illuminator.

Mr. Murdoch, Mr. Southern, Mr. Clegg, and Mr. Henry Creighton, all resided at Soho, near Birmingham, at the same time; and without doubt Mr. Murdoch used coal-gas for the purpose of lighting his house and offices at Redruth in Cornwall in the year 1792, and four or five years afterwards he introduced the system into Scotland. In the year 1798 he constructed an apparatus upon an extensive scale at the great manufactory of Bolton and Watt, near Birmingham, where the first attempts were made to purify the gas; and at the peace of 1802, the manufactory at Soho was illuminated by it with a variety of devices on the exterior, to the astonishment of all who beheld it.

Various manufactories were afterwards lighted with coal-gas, but it was not used in the streets till the year 1807, when a portion of Pall Mall in London was illuminated by Mr. Winsor, who proposed the establishment of a national light and heat company. The retort used on this occasion to distil the coal was an iron vessel, with a cover well-fitted and luted to the top; in the centre of the lid was a pipe, which conveyed the gas to a condensing vessel of a conical form; this was divided into two or three separate compartments by plates bored with a number of holes, so that the gas might spread, and more readily purify itself from the sulphuretted hydrogen and ammonia, which it did, though very imperfectly. The pipes laid down as mains were lead, with copper burners to the branch pipes, which were argands, jets, and batswing, as in present use.

Dr. William Henry gave a series of lectures at Manchester in the year 1804, and during the course he exhibited the mode of producing gas from coal, and its use as a material for yielding light. Mr. Samuel Clegg at this time, having left Soho, began to direct his attention to the construction of gas-light apparatus, and one of his first works was lighting a cotton-mill near Halifax in Yorkshire. The subject was soon afterwards taken up by Mr. Josiah Pemberton, of Birmingham. His apparatus consisted of a cast-iron vessel, like a cottage pot, and would contain from 15 to 30 pounds weight of coal; a strong cover with a pipe fitted on carried the gas to the purifying cistern, ascending and descending in its passage through the water; it was thus well condensed and washed before it entered the gasometer, which was suspended by a weight over a large wooden vat. The pipes that carried the gas were made of tinned iron or copper.

In the year 1809, an application was made to parliament for the establishment of the present London and Westminster Chartered Gas Light and Coke Company: this was opposed by Mr. Murdoch, on the ground of his having a priority of right to the discovery, but it was eventually embodied by legal authority, and having a large capital at command, the works for lighting the streets were commenced; but the subscribers becoming dissatisfied with the proceedings, a change of management took place, and in 1812 a charter was granted for the term of twenty-one years. The following year, by the assistance of Mr. Samuel Clegg, great improvements were introduced throughout all the operations, and to him we are indebted for the horizontal rotative retort for purifying coal-gas with cream of lime, for the rotative gas-meters, and for the self-acting governor: he also greatly improved the

retorts, and the manufacture of gas was rendered so perfect, that its general adoption was the consequent result.

In 1817, this gas company had three stations, which consumed daily 25 chaldrons of coals, producing 300,000 cubic feet of gas, which was equal to the supply of 75,000 Argand lamps, each yielding the light of six candles. At the City gas works in Dorset Street, Blackfriars, 3 chaldrons of coals were daily carbonised, which was equal to the supply of 1500 Argand lamps, so that the two companies supplied 76,500 lights. During the last few years many new companies have been established, and there is scarcely a town in the kingdom without this invaluable addition to its comfort.

In the year 1834, in the city of London and its suburbs alone there were 168,000 gas lamps, which consumed nightly 4,200,000 cubic feet of gas; requiring for its manufacture 10,800,000 cubic feet of coal. And by a document laid before parliament three years afterwards, it appears that there were eighteen establishments, besides twelve chartered companies, employing a capital of 2,800,000*l.*, whose yearly revenue was 450,000*l.*; that they annually consumed 180,000 tons of coals, and made 1,460,000,000 cubic feet of gas, which was supplied to 134,300 private burners, used by 40,000 consumers, and 30,400 street lights: 176 gas-holders, which contained 5,500,000 cubic feet of gas, were employed; 890 tons of coals were consumed in the retorts during the longest night, or 7,120,000 cubic feet of gas. In the five years between 1822 and 1827, the quantity of gas made was doubled; and from that time to the year 1837, it had again doubled itself.

Prisons, according to Palladio, "should consist of three descriptions: one for those who are kept confined until a reformation of manners can be effected; another for criminals who are to be tried, as well as those already condemned, and a third for debtors; these ought to be well secured and guarded against internal and external violence, healthy and commodious, because they are for the safe keeping, not for the torment and pain of criminals, or of other men; their walls therefore in the middle should be formed of massive stone, bound together with cramps, with bolts of iron or other metal, and then lined on both sides with brick, to prevent any humidify, and to make them healthy. Passages should be made all round them, and the rooms for the keepers should be near at hand."

At Milan and other towns of Italy, there are such prisons, but in England little attention was paid to the subject until taken up by the philanthropic John Howard, towards the latter end of the last century. This illustrious individual, after visiting most of the places of confinement in Europe, induced the government to establish penitentiary houses, upon the principle of some already founded in Holland, where it was considered, that if offenders convicted of crimes, for which transportation had been usually inflicted, were ordered to solitary imprisonment, accompanied by well-regulated labour and religious instruction, it might be the means, not only of deterring others from the commission of the like crimes, but also of reforming the individuals, and inuring them to habits of industry. The reformation and amendment of the prisoners was here for the first time made the chief end of imprisonment; and to carry out this excellent idea, Dr. Fothergill was associated with Howard to devise a plan and provide a site for a structure in which it could be fully developed. The cloth-hall at Halifax was the model for the building, whilst the regulations were to be those of the Rasp and Spin houses in Holland. The plans and elevations are given by Howard in his account of prisons, and consist of six courts, each surrounded by three stories or tiers of open galleries, around which are distributed the cells for the prisoners; a portion of ground near Islington was selected for its erection, the neighbourhood being considered healthy, and a supply of water could be easily obtained; it was also sufficiently removed from any habitation.

Regulations were laid down for security, health, diet, clothing, lodging, firing, religious instruction, employment, rewards, punishments, sickness, and general government. These works were, however, not carried out during the life-time of Howard, and after his death were abandoned for some time. In the year 1770, the mortality among the prisoners at Newgate was so great from the gaol distemper, that Mr. Akerman, the then keeper, stated, that independently of the prisoners, nearly two sets of servants had died since he had been in office; and that in the year 1750, two of the judges at the Old Bailey, the Lord Mayor, several of the jury, and others, to the number of sixty persons, died of the same disease; after this had occurred, a large ventilator, with sails like a windmill, was placed on the top of Newgate to produce a circulation of fresh air.

Parliament subsequently granted 50,000*l.* to construct a new gaol; this was completed under the superintendence of Mr. George Dance, a little before the riots of 1780. This prison, which has a frontage of nearly 300 feet, is admired for its appropriate and massive character. The centre is occupied by the keeper's house, with the entrances on each side; the walls are of Portland stone, rusticated and continued up to a height of 50 feet, the whole producing by its magnitude and boldness of detail a very characteristic façade. The interior distribution is defective, in consequence of the want of space, the site on which it is erected being far too small to allow of a proper ventilation or a requisite supply of air.

This prison has three distinct arrangements, which are called stations. The first, in the north wing, has three yards, with sleeping and day rooms attached: the first yard and rooms are occupied by adult convicts; the second by boys, who have a school-room; and the third is an infirmary.

The principal wards and rooms in the stations are 38 feet by 15, and 24 feet by 15. The two connected with the press-yard, for males under sentence of death, are 31 feet by 18. There are three tiers of condemned cells, five in each tier, strongly arched, 9 feet by 7. In each cell is a barrack bedstead. The chapel will contain 350 persons.

Other prisons have since been erected about the metropolis, as well as in several of the counties in England; there are also numerous bridewells and penitentiaries, upon which enormous sums of money have been expended, but that most deserving of notice is the Model Prison lately erected at Pentonville, in which all Howard's ideas are carried out. It was reserved for the present day to execute the plans suggested by this philanthropist, upon the site he had selected. The first stone was laid on the 10th of April, 1840, and the whole was completed in the autumn of 1842. It is adapted for the reception of 520 prisoners upon the separate system, each having a cell 13 feet by 7, and 9 feet in height.

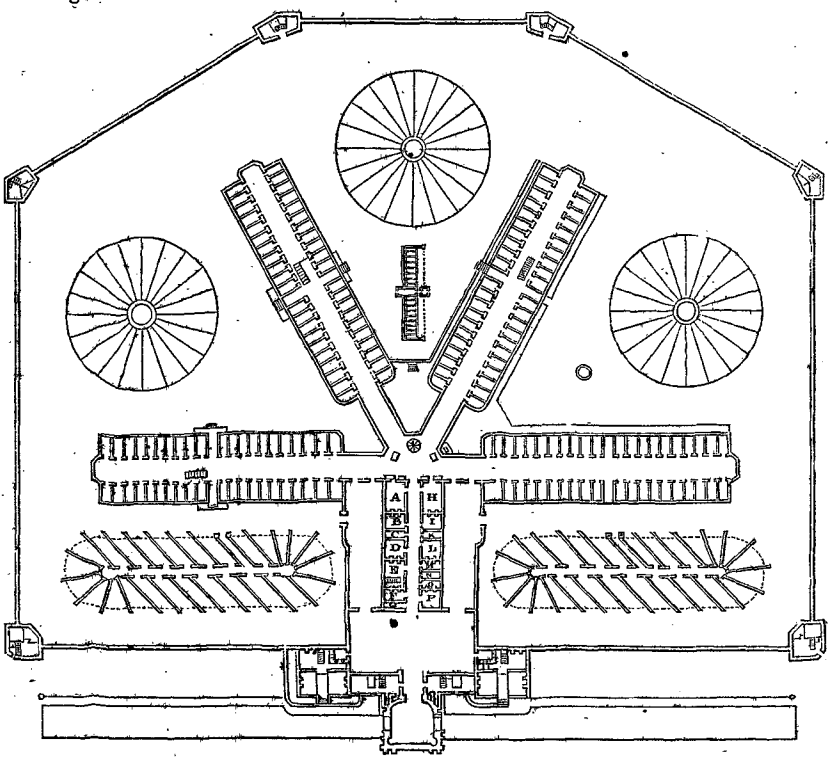


Fig. 559. PLAN OF THE MODEL PRISON.

The plan exhibits a central hall, open from the floor to the roof, from which branch five blocks of building, each having on the ground floor a corridor, which extends the whole length, with galleries above, in which are the entrances to the cells, arranged on each side against the outer walls. From the central hall the doors of all the cells may be seen, as the galleries are formed of open iron-work. The Eastern Penitentiary at Philadelphia, designed by Mr. Haviland, seems to have been the prototype for this arrangement. As there are no female prisoners there is but one class of cells.

The boundary wall is upwards of 20 feet in height, and solidly constructed, and on the outside is an open space of considerable width. The basement is not sunk into the earth, except in one portion, where it has an open area; over the whole surface of the walls a course of slate in cement was laid 6 inches above the ground line, and the walls stand on a

bed of concrete 3 feet in depth and as much in width, so that every precaution is taken to prevent the ascent of moisture. Under the entrance building is a ward for the reception of prisoners, where they are examined by the medical attendant. The access to this ward is from the ground floor, near the entrance door; and the accommodation consists of a receiving room, a number of cells in which prisoners can be locked up for twenty-four hours if necessary, an examining room, clothing stores, bath, and a closet for fumigating and purifying clothes. This ward has no connection with the rest of the basement, but prisoners, after being examined, cleansed, and dressed, are taken into the prison through the entrance passage on the ground floor. The basement under the great central hall is used for the distribution of materials, and is surrounded by a covered passage, which communicates with the kitchen, yards and stores, &c. Adjoining the kitchen is a room in which the provisions are weighed out and arranged in trays, after which they are hoisted by an apparatus to the different stories, and distributed to the wards. The remaining portion of the basement is used for offices, punishment cells, and the attendants.

The ground plan shows the distribution of the building, the exercising yards, the entrance gates, and two front barriers; the well for supplying the prison with water; the houses for the governor, chaplain, and gate porters.

Besides the 520 separate cells, there are twenty others on the basement used as workshops, &c.; a chapel, which contains stalls for 256 prisoners; a board room for the commissioners, A; offices for secretary, B, governor, H, chaplain, D, physician, E, governor's clerk, N O P, clerk of the works, &c., waiting room, G, visiting room for prisoners' friends, L M, schoolmaster's room, library, surgery, offices for the steward and clerk, kitchen and scullery, stores for provisions, &c., stores for manufactured articles, dwellings for governor, chaplain, assistant chaplain, steward, and manufacturer, principal schoolmaster, clerk of the works, four principal warders, twelve warders, two gate-keepers, one messenger, an engineer, and apartments for the deputy-governor, resident medical officer, and infirmary warden. The total area, including the boundary wall, is 6 acres 10 perches; there is a garden of 2 acres in the rear, and a terrace and road 75 feet broad in front.

The chapel is 72 feet 6 inches in length, 40 feet in width, and 26 feet in height to the under side of the cornice, above which is a coved ceiling. It occupies a portion of the upper part of the building, and is entered on the level of the first and second galleries. The rows of seats are so disposed that the prisoners are effectually separated from each other, whilst, at the same time, each has a view of the officiating clergyman, and can be seen by the attendant inspector. Each prisoner, as he enters, closes the door after him, and when a row is filled the officer fastens the whole of the doors in the row by a handle and crank, which are shown in the cut.

There are four entrances, and, by means of a sliding partition drawn across the gallery, the whole can be filled in seven minutes. When service is over, a signal is made by means of a letter, which designates each row, and the prisoners occupying the seat corresponding with it retire.

The plan of the stalls shows the doors shut, half shut, and entirely open, in the three different rows; the clear space allowed each prisoner is in width 20 inches, and in depth 32, the width of the seat being 9 inches out of it.

The section shows the stepping up, so that each prisoner may obtain a view of the clergy-

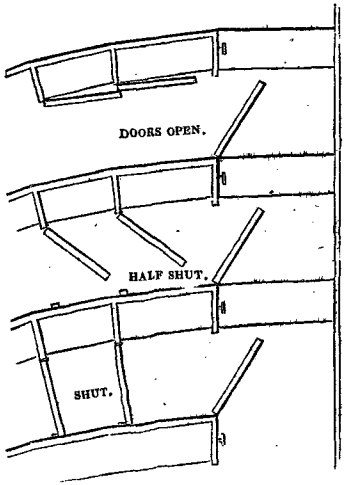


Fig. 560. PLAN OF STALLS.

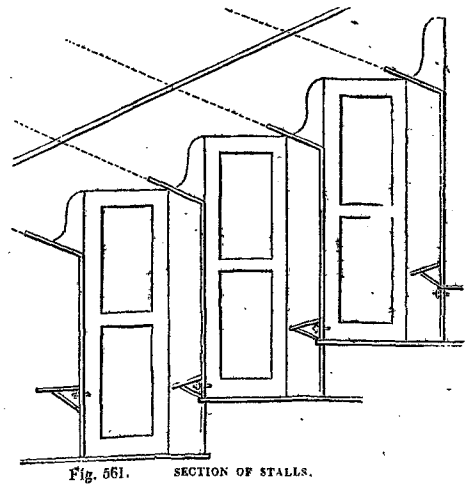


Fig. 561. SECTION OF STALLS.

man: the heights of the divisions up to the top of the reading-desk is 4 feet 6 inches, the width of the reading-desk 16 inches, and the height of the doors above the floor of each 6 feet. By this arrangement the prisoners on the rear and front are prevented from seeing each other.

The fastenings for the hall doors are shown in plan and profile with the jointed handle; they are made of brass. When the doors are closed, the handle falls downwards, and when open its position is as shown in the figure to the left. On the plan the fastenings, when the doors of seats are closed, assume the horizontal direction.

The cells are each divided by a wall two bricks in thickness; the external walls are two bricks and a half. The ceilings are formed of half brick arches, worked in cement, over which is laid a bed of concrete, about 6 inches in depth; this is levelled, and on it is placed the floor of asphalte for the cells above. The whole thickness from the floor of one cell to the ceiling of the other is 12 inches. In the upper cells, for the purpose of greater security, is a brick arch, nine inches thick, worked in two courses in cement, with a layer of hoop iron laid diagonally at intervals of 4 inches.

The cells are 13 feet in length, 7 feet in breadth, and 9 feet in height to the under side of the arched ceiling. The window-frame, which is fixed, is of cast-iron, glazed with fluted glass, having outside two strong iron bars so placed that they do not intercept the light. The door has a spring lock, and a small trap is contrived for the introduction of provisions; there is another opening, covered by a movable flap, for the purpose of inspection.

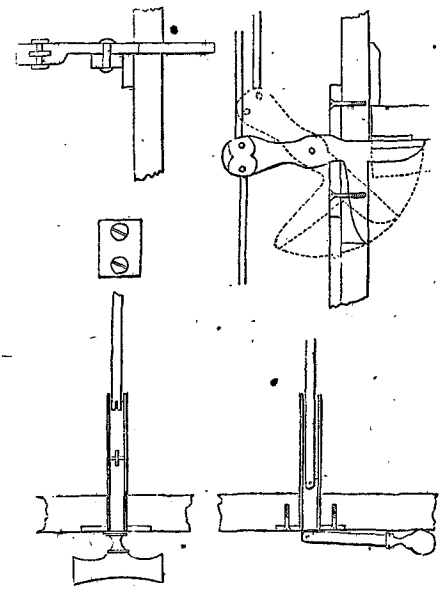


Fig. 562. HANDLES TO DOORS OF CHAPEL.

These cells are well adapted to carry out the reformation and amendment of their inmates: to such the philanthropic Howard, who did not approve of any suffering capitally but for murder, setting houses on fire, or house-breaking attended with acts of cruelty, would have consigned all those unhappy wretches who had committed less heinous faults, that they might, by regular and steady discipline, have the chance of becoming useful members of society, and he ardently indulged in the hope that it was possible, in the course of five years, to effect this; and with such accommodation and treatment as the prisoners receive, with airy apartments, warmed, ventilated, and plentifully supplied with water, they cannot but enjoy better health than falls to the lot of many mechanics and day labourers, who, neglecting cleanliness, and not receiving wholesome and proper food, often die at a premature age. In these cells there is ample space for any work assigned to the prisoner, and as a proper degree of labour is conducive to health, he that has led an idle life previously may not only acquire industrious habits, but with them strength of mind and body: there are many who would fancy the inmates of these solitary rooms far too comfortable, but they should remember that the object is to reform the prisoner, to oblige him to reflect, review his past life, and form resolutions to amend, which may tend to his becoming a better citizen. Punishment, unaccompanied by sympathy for the distresses of the offender, is not likely to be a corrective; the human heart is not so to be softened; on the contrary, a feeling of anger will be induced, leading to the commission of greater crimes, until the last dread penalty of the law is inflicted.

Habits of decency, order, and regularity being obtained, the prisoner has advanced towards the threshold of religion, for which he is infinitely better prepared than he would have been by the most rigorous severity. Experience gives us daily proof that criminals may be reformed, and if so, every county and populous district in the United Kingdom should have its penitentiary-house or prison: the hulks and common gaols would no longer contaminate the young, who are often sent thither for faults arising from a neglect of education, and where they imbibe ideas imparted by the most abandoned, and return to society a greater nuisance and dread than before they were committed. The bettering-houses in Holland proverbially benefit those who enter them, and there are few instances in which

solitary confinement, with careful supervision, has any other effect than that of ameliorating the condition of the prisoners. The grand object of education should be to make

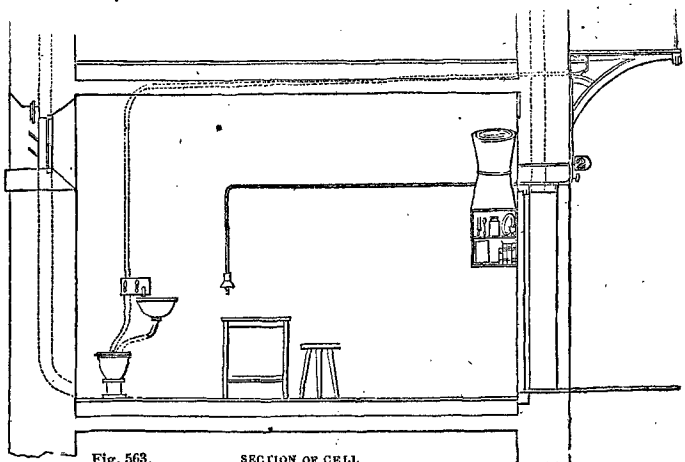


Fig. 563. SECTION OF CELL.

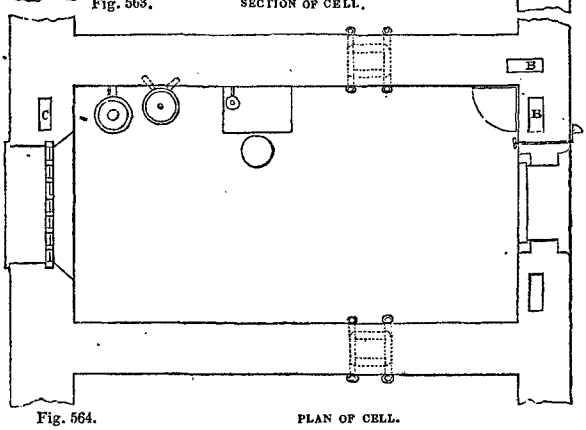


Fig. 564. PLAN OF CELL.

men think, and the opportunity to do so can only be afforded when they are removed from haunts in which they see and hear what stimulates them to actions of wrong, and receive no inducement to do what is right: notions on these subjects may possibly never have been presented to them, and when committed to the care and superintendence of the officers of such establishments, they may, for the first time, be led to comprehend that their own means of subsistence is not necessarily connected with injury and outrage towards their fellow-creatures; and what may be the result of such a dawn in the mind, no one can predict. Cleanliness in this establishment is strictly attended to; all the provisions with which the prisoners are served are of the best quality of their kinds, and the proportions duly given out to each. Water is abundantly supplied from triangular cisterns, fixed in the angle of each cell; the gaslight is immediately over the table, seen in the section, to the right of which is placed a three-legged stool; under the window is the earthenware basin and water-closet: these are all shown on the plan, and are more especially detailed in the several figures which succeed. The works for all these conveniences, particularly those of the plumber, are admirably executed, creditable alike to the workman and the architect. In the management of such apparently simple details far greater ingenuity is required than is generally imagined or is usually bestowed upon them, and at this prison they are models of their kind.

The double supply cock, which communicates with the washing-basin and soil-pan, is

enclosed in an iron frame, which protects it from injury. The pan and parts connected with it are of strong glazed earthenware.

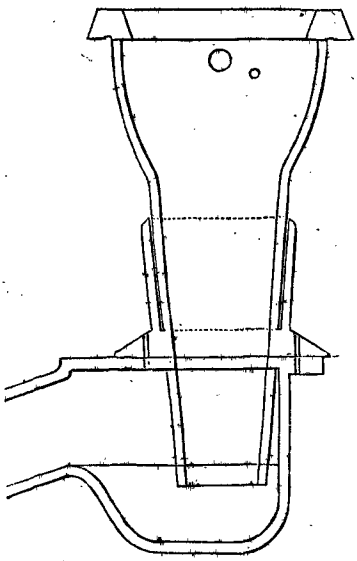


Fig. 565. EARTHENWARE SOIL PAN.

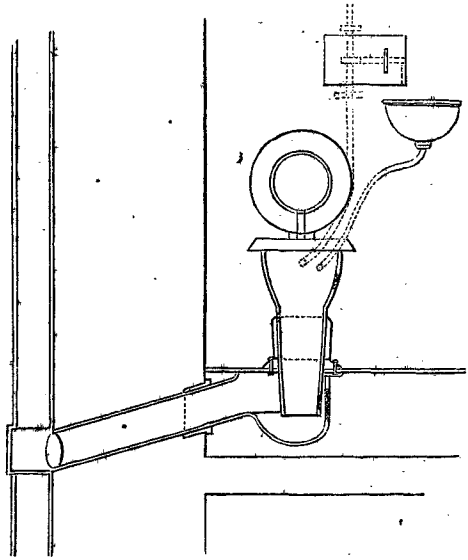


Fig. 566. SECTION OF SOIL PAN, TRAP, BASIN, ETC.

The cells are lighted with gas, and the water-troughs and service-pipe are well contrived. The troughs are of iron, 6 inches in depth and 4½ inches wide; these are cast in lengths of 8 feet 6 inches, which correspond with the width of the cell; they are supported on brackets, and in order to limit the quantity of water, there is a division to which each prisoner has access, containing a cubic foot, or six gallons. The troughs are supplied from cisterns placed on a level with each range.

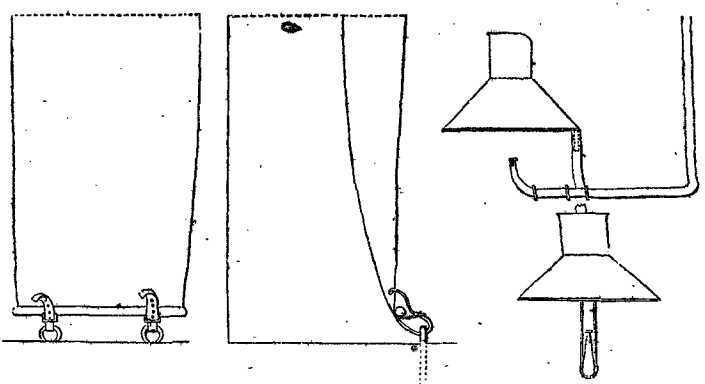


Fig. 567. GAS LIGHTS AND WATER CISTERNS.

By a reference to the plan of these arrangements it will be seen that the greatest economy has been adopted. The pipes are all trapped in such a manner that no effluvia can pass along the soil-pipes or find its entry into the adjoining cell; the party-wall between the two is of a sufficient thickness to prevent all sound, and the junction of the two wastes takes place on the outside of the building: wherever the water that has been used for washing or other purposes is allowed to run away, it is made available for purification; the waste of the wash-hand basin passes through the pan of the closet, which is united to a D trap.

The gas-burner is provided with a pipe for the escape of the unconsumed carburetted hydrogen, which, when the light is burning, also contributes much to the purification of the air in the cell. No opportunity seems to have been lost for rendering everything necessary for the prisoner's use available for maintaining a free and regular ventilation: the quantity of air necessary for combustion, as well as to supply the loss of that which is deteriorated by respiration, has all been provided for; and a very small room, in which these matters have been considered, is far more healthy than one of large dimensions where they have been neglected. In our crowded bridewells and prisons no provision was made either for ventilation or for the removal of accumulated filth: to walk through such a building produced feelings the very opposite to those which we experience in this well-ordered and cleanly model prison; many were without a common sewer; cesspools were the only receptacles, covered with temporary boards, or some other material easily taken up, for the purposes of constantly removing the contents: hence it could hardly be supposed that gaol fever could be eradicated, or that the walls, with the constant lime-whitening to which they were subject, could be free from putrescence or infectious miasma: when contrasted with the underground dungeon of the middle ages, our receptacles for prisoners may be considered as an important progress in civilisation.

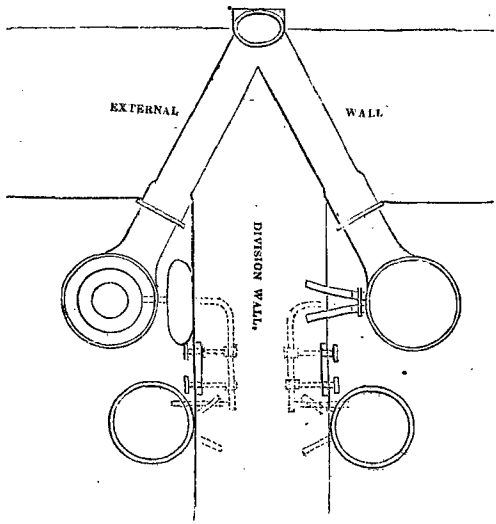


Fig. 568. PLAN OF BASINS IN THE TWO ADJOINING CELLS.

The interior of the frame, from which the supply-pipes and cocks branch to the several basins, is shown in the annexed figure.

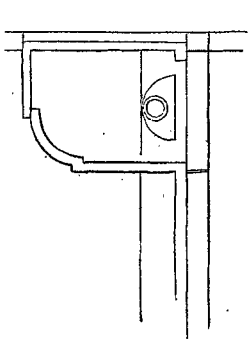


Fig. 569. PLAN OF WATER CISTERN.

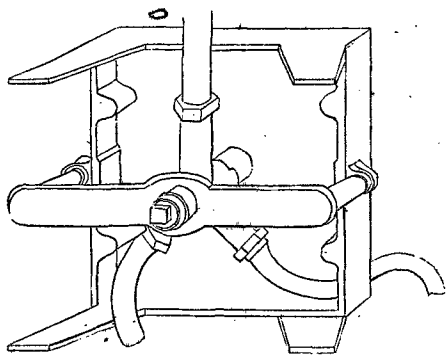


Fig. 570. FRAME SHOWING THE SUPPLY COCKS.

The central hall and corridors, which are open from the pavement to the roof, enable the officers on duty to see all that passes to the door of each cell. Each block or wing is called a division, and distinguished by letters, A, B, C, D. The cells on the ground floor, and on the level of the galleries of each division, are wards in the division to which they belong. The ground floor is No. 1., the first gallery No. 2., and the upper gallery No. 3. Ward. The cells in each ward are numbered consecutively, the odd numbers being on the left-hand side when looking from the centre hall, and the even numbers on the other. Each prisoner has a small brass plate, which is suspended to his button, on which is engraved the designation of his cell, the letter of his division, and the number of his ward.

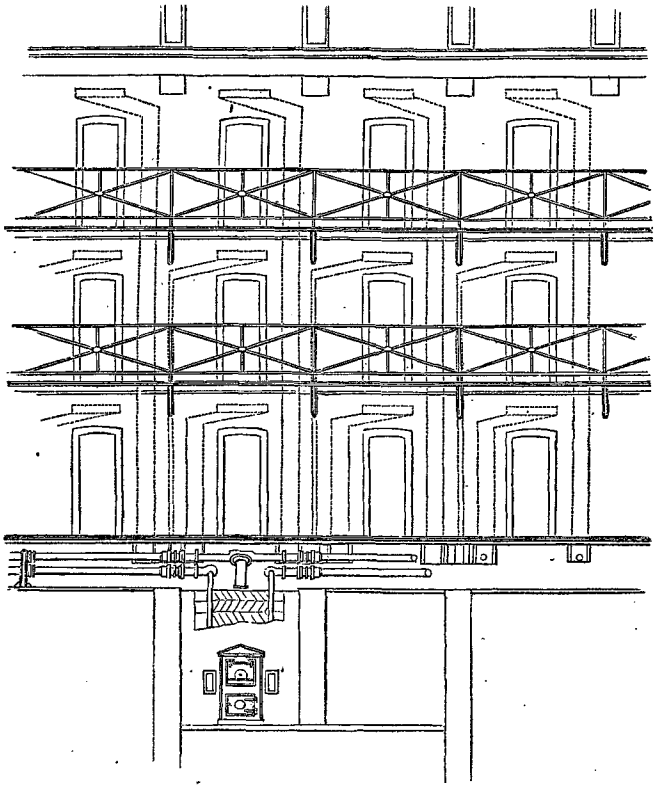


Fig. 571. ELEVATION OF PART OF CORRIDOR.

The prisoners can communicate at any time with the officers of the prison by means of a large bell or gong in the centre of each line of cells. A handle attached to a label and

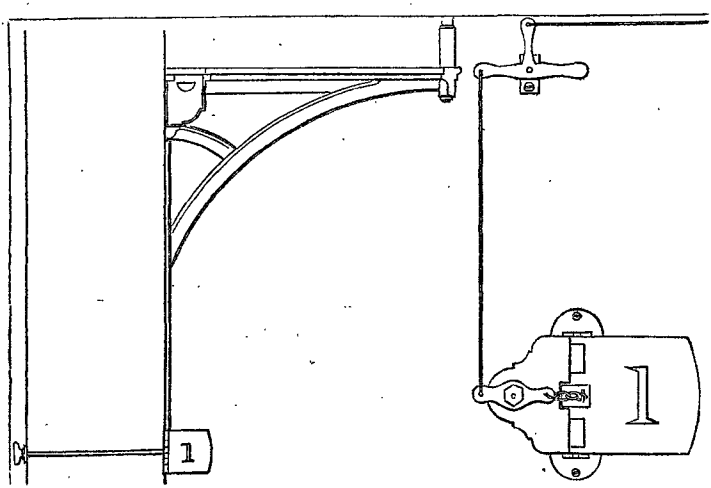


Fig. 572. LABEL IN THE CORRIDOR WHEN SHUT AND OPEN.

crank is placed in every cell, and a single wire and crank communicates with the bells. When the handle is turned the label flies open, a single stroke is sounded, and a pendulum connected vibrates with it; thus the attention of the officer on duty is attracted, and the label, which remains open, indicates the cell where his presence is required.

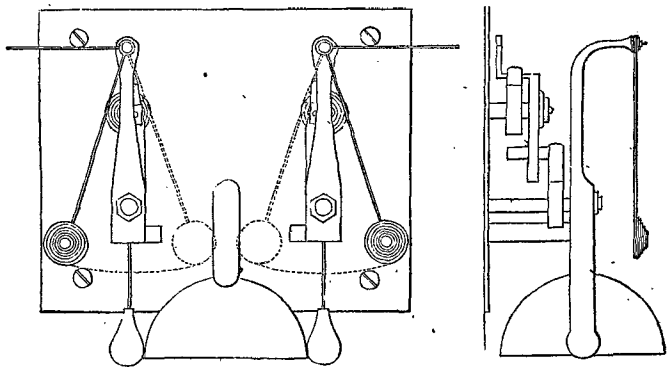


Fig. 573. ELEVATION OF GONG. SIDE ELEVATION.

The exercising yards radiate from a central point, round which there is a passage of communication, and an inspection into each is obtained through a large orifice in the door, covered by open wirework. The space within the passage forms a room with windows above, which command each yard. The yards have an open railing on the outside, to allow a free circulation of air, and one portion is roofed in to afford shelter, if required. In the centre space is a water-closet, and there is an easy access to all the cells. There are altogether 114 exercising yards, which exceeds a fourth of the prisoners, so that each has one hour's exercise in every four hours.

The baths are very simple in their arrangement; there are eight, which admit of thirty-two prisoners bathing each hour, and every one must bathe once in fourteen days.

The advantages which the prisoners derive from this judiciously arranged portion of the Model Prison are incalculable, and worthy of imitation by the directors and governors of all the gaols throughout the world. The expense attendant upon cold, tepid, or a warm bath, is so inconsiderable, compared with the comfort derived from them, that it seems extraordinary any establishment should be without them. Numerous plans have been submitted to the government at various times to establish public baths, and in some large towns in the neighbourhood of the factories they have been erected at a considerable expense, and found highly beneficial: the health of all the labourers and artisans resorting to them has been so infinitely superior to those neglecting this benefit, that the absolute necessity of their introduction in all prisons is most obvious, where confinement prevents that exercise which produces free circulation, and consequent healthy state of skin; for this the bath is an excellent substitute. But perhaps one of its most important services in prisons is the producing notions of cleanliness in the prisoners, which they may carry with them when restored to society; and the squalid misery, so often the companion of poverty, may thus become less common, through the influence of those to whom we should not generally look for reformations, the discipline of the prison would then become a blessing instead of a curse.

The ample supply of good water throughout the Model Prison, and the judicious manner in which it is distributed, tends to promote the comfort of those occupying the solitary cells. By a reference to the cost of the pipes and hydraulic arrangements, it does not appear that each cell has had expended upon it more than 40*s*., and this amount includes all the requisites for a prisoner with regard to the supply of water. Such beneficial results are rarely found united in our public buildings with so much economy, and are deserving the consideration of those who have the management of our hospitals, union workhouses, and similar establishments. By a reference to the evidence taken before the Commissioners of Inquiry into the State of Large Towns and Populous Districts, we see many valuable hints to benefit the residences of the poor, but none in which the estimate is so small, and productive of such vast advantage.

The hoisting machine, by which the trays containing provisions or materials are raised from the basement to the level of the ground floor and galleries above, is fixed in the basement on each side the central hall, and affords a direct communication between the kitchen

and the wards. The trays are conveyed along the ground floor in a small truck, and along the galleries, or upper wards, by a light trussed iron carriage, which traverses on the top of the gallery railing. The front and side views of the machine are at the top of the figure; the power which hoists it is placed on the floor line of the basement; its profile and

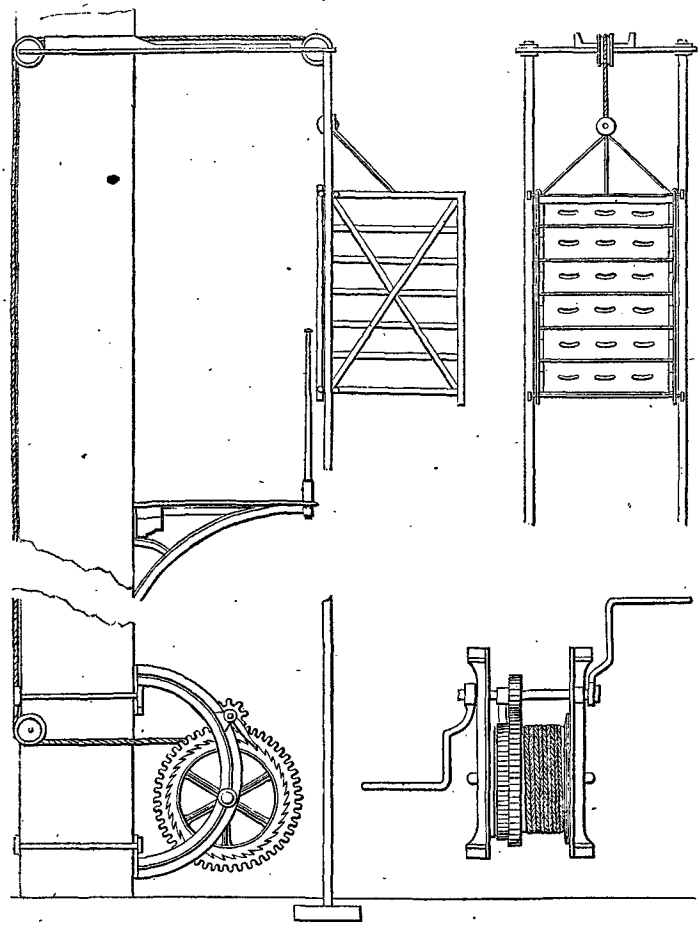


Fig. 574. MACHINES FOR RAISING PROVISIONS.

arrangement are shown below, as are also the plan, side, and end elevation of the iron carriage which traverses the galleries.

The different rations or allowances for the prisoners, being placed in large trays, are thus conveniently mounted from the basement floor, where the kitchen and magazines for the provisions are situated. When they have arrived at the level of the gallery where they are intended to be distributed, the horizontal bar at the top of the balcony on each side becomes a railroad, upon which the light iron carriages make their passage from one end of the corridors to another: the officers in attendance who have the distribution stay the carriage at the door of each cell, and give out the requisite meal. There is immense convenience derived from this simple arrangement, the whole passes so steadily that it arrives at its destination exactly in the same state in which it sets out; there is no confusion or waste by any article being broken or spilt by the way; by these mechanical means the food is served to the prisoners with such despatch, that it runs no risk of being cooled in its passage up long flights of stairs, or through the corridors.

The plan in the accompanying figure shows the position of the four wheels which run

upon the top of the railing of the balcony, in front of the doors of the cells; the whole is firmly braced together and bound by screws: the upper part of the figure represents the elevation of the iron framing, and the two wheels placed upon the edge of the railing: the middle figure is the section or elevation of the carriage in the other direction. By the bracing or trussing introduced beneath the frame, it is rendered capable of carrying a considerable weight, and from the care used in arranging it, there is no apparent tendency to force out the vertical position of the balcony railing. When the crab or windlass in the basement is worked, the whole mounts in a perfectly steady manner, without any irregular action, and thus continues to the end of its destination: the materials given out to the prisoners from the warehouses below to be manufactured are all hoisted in the same manner, and when wrought so descend to other depôts. So ingenious a contrivance would be of the greatest service in our public establishments, and ought to be more generally introduced: some years ago the writer contrived similar machinery for the great laundry at the top of the Burlington Hotel in Cork Street, which he erected, and which has been found of essential service to that establishment, from the great economy of labour.

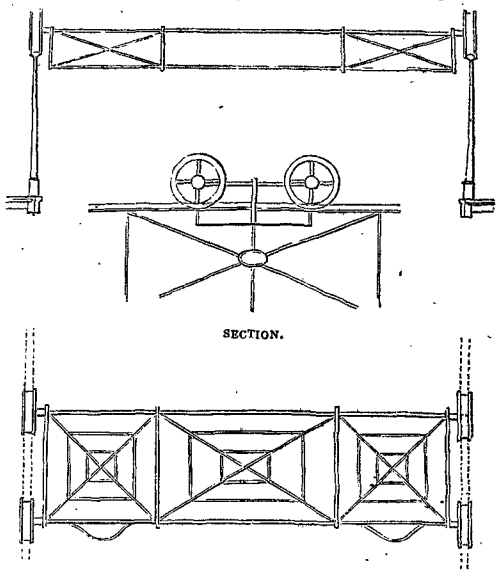


Fig. 575. PLAN AND SECTION OF CARRIAGE.

In detailing the several contrivances here introduced, we are struck with the differences presented to us in comparing them with the general state of prisons up to the end of the last century: let us take for example the description given by a French writer of the Conciergerie, which was formerly a portion of the Palais de Justice, and still preserves its ancient feudal character: "the towers, the entrance court, the dark corridor by which the prisoners pass, produce a sensation of melancholy and terror; those condemned to remain there, if not provided with sufficient money to pay for the hire of a bed, must lie in dark, damp, and fetid cells, straw only being allowed, amidst a number of other wretched individuals: the vast court, constructed in the thirteenth century, in which the prisoners take exercise, is sunk 10 or 12 feet below the level of the neighbouring streets; their food is confined to one ration of poor bread and thin soup." In other prisons, we find the cells were not sufficient in height for the inmates to stand upright. The minister Necker interested himself most ardently in endeavouring to remedy many of these evils, and was successful in some particulars. In the House of Correction at Ghent, commenced in 1773, during the reign of Maria Theresa, great improvements were introduced, which awakened consideration to the subject throughout the continent; fire-places were constructed, and the cells were made of a dimension sufficiently ample for the number they were to contain; light and air were admitted, and cleanliness was encouraged and enforced; exercise was allowed to the unhappy individuals, and they were no longer punished by their allowance of food being withheld.

Regulating cistern, pipes and cocks for the distribution of water. The cisterns are placed in the roof, which has a rising main, together with a service-pipe, and two rows of troughs, divided into compartments, containing six gallons, or one day's supply for each cell. There are also regulating cisterns, and ball-cocks for turning on and shutting off the water to the troughs.

The supply pipe for the upper troughs is connected with the main service pipe, and runs to the extreme end, where it fills another trough, which then overflows, and supplies another, and so on, till all are filled. The last is furnished with a waste-pipe, to convey the surplus water into the regulating cisterns, which, raising the ball as it fills the cistern, acts upon the stop-cock to which it is attached, and shuts off all further supply to the troughs on the roof. The troughs under the upper gallery floor, for the use of the cells beneath,

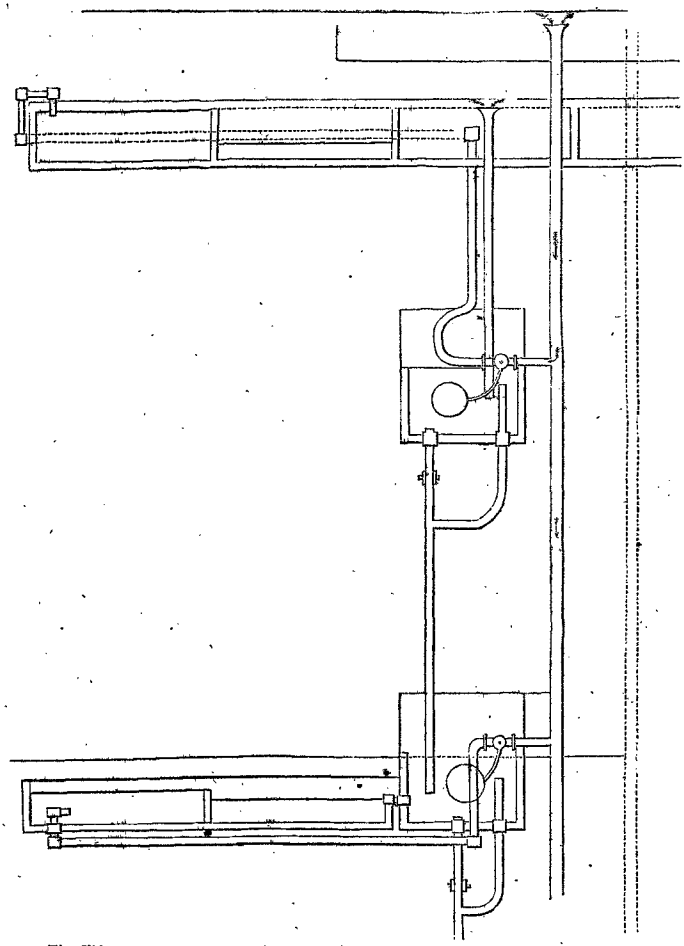


Fig. 576. PIPES TO CISTERN IN ROOF.

are supplied by a pipe fixed under the troughs; the water is allowed to flow successively into the cisterns, and is shut off as above.

Ventilating. — An artificial system of ventilation has been adopted, with a view to produce at all times and seasons an abundant supply of fresh and wholesome air; this has been attended with some difficulty in a prison where each prisoner has a separate cell, and the window of that cell necessarily obliged, for the sake of security, to be closed. Health is of the first importance, and considerable attention has been paid to the subject; but there yet seems to be something wanting, on entering one of these cells, to make it apparent that a pure and agreeable atmosphere is breathed. The objects aimed at have been the withdrawal of a stated quantity of foul air from each cell; the supply of an equal quantity of fresh air, without subjecting the prisoner to a draught; the means of warming it, when necessary, without injuring its qualities, or affecting its hygrometrical condition, and the avoidance of additional facilities for the transmission of sound by the air channels or flues.

The apparatus for warming the air is placed in the centre of the basement story of each wing: it consists of a case or boiler, to which a number of pipes for the circulation of hot water are attached. In connection with it there is a large flue open to the external air, which is introduced through this opening, and, after passing over the surface of the boiler, turns, right and left, along a main flue, which runs horizontally under the floor of the corridor, and from thence passes upwards, through small flues in the wall, which terminate

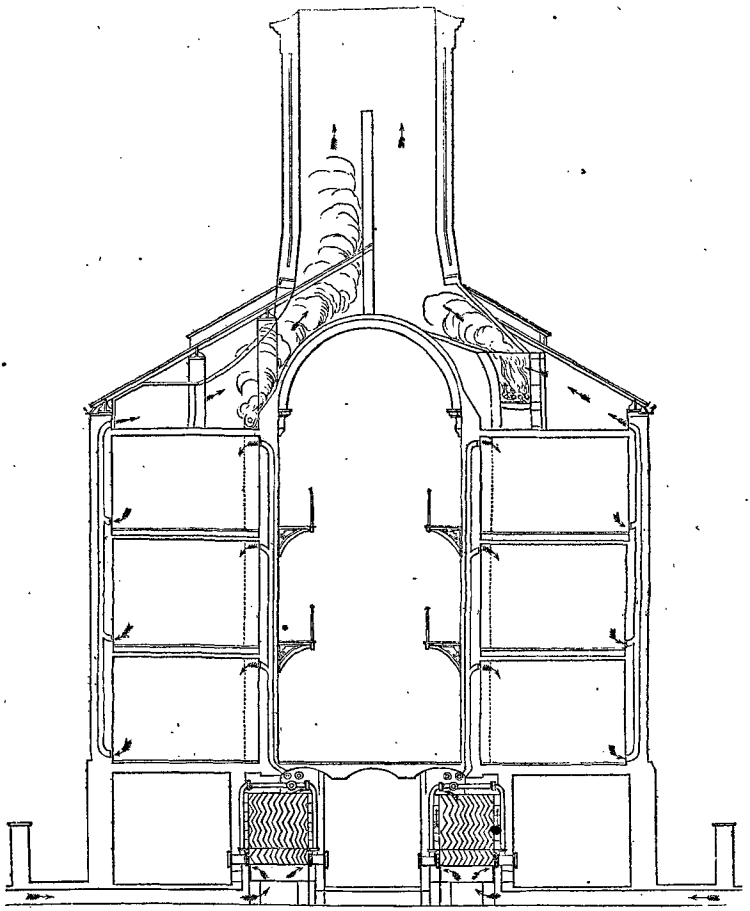


Fig. 577. TRANSVERSE SECTION OF PRISON.

respectively in a grating placed close under the arched ceiling of each cell, into which a current of air is thus introduced.

It is very difficult to lay down a plan for the ventilation of public buildings, particularly as the sites and uses present so much variety: the various improvements that have been suggested on this subject for deep mines, and in some instances carried into effect, have turned the attention of the architect and civil engineer to adopt some method that shall insure a stream of pure and properly tempered air to follow the exhaustion that takes place in our churches, halls of assembly, or wherever great masses of people meet together and are confined for any length of time; in a future part of the work the subject will be more fully treated. It does not appear that attempts were made to renovate the atmosphere of the cells of our prisons until practised here: much has been judiciously effected, but, with all the precautions hitherto adopted, none have yet been found to answer perfectly. Temperature and pressure exert so many influences, and, in conjunction with radiation and evaporation, so change the properties of the air, that it is exceedingly difficult to construct by means of pipes, valves, or machinery, contrivances that shall counteract or mitigate them. The section of the windows represents by the arrow-heads the current that the air takes in its passage, and the escape of the foul air to the outside of the cell: the handle attached to the valve that admits the warm air is at the prisoner's command; he can consequently introduce the desired quantity at pleasure; the windows are so formed that thorough ventilation is obtained.

The window frames are formed of iron: their plan shows the manner in which they

are rebated to receive the glass, and the section at the side of the opening shows its position; the whole is barred to prevent the prisoner making his escape, at the same time in such a way that the light is by no means obstructed. In the plan and section of the cell previously given, its position and height from the floor may be seen; as it is placed immediately opposite the door by which the prisoner enters, which is also provided with a grating, there can be obtained a thorough current of air, if it is desired; the parts marked B and C in the plan of the cell show also the situation of the fresh and foul air shafts or pipes obtained in the thickness of the wall. The external walls, in which these window openings are made, is 1 foot 10½ inches, and that of the walls between the cells is 18 inches in thickness. The whole of these fittings are executed in a most substantial manner, and the frame is so strongly bedded in the brickwork of the outer wall, that it would be difficult to disturb or displace it.

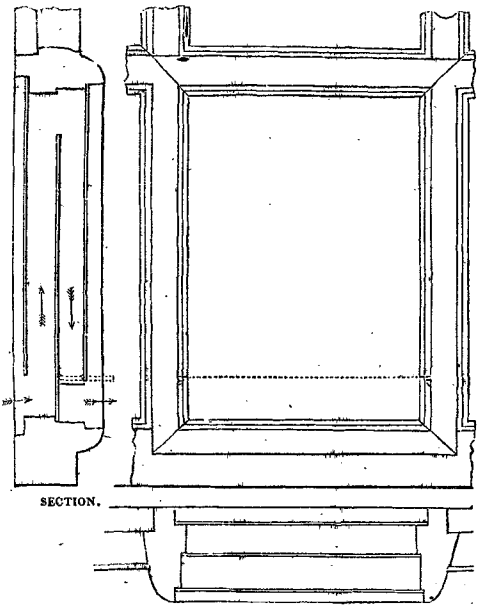


Fig. 578.

The foul air is removed by means of a grating, placed near the floor of each cell, on the side next the outer wall, and diagonally opposite the point where the fresh air is introduced; this grating covers a flue in the outer wall, opening at its upper extremity into a horizontal foul air-flue in the roof, communicating with a vertical shaft, raised upwards of 25 feet above the ridge. Thus, by the outer air passing the warming apparatus to the top of each cell, and thence from the floor upwards, through the extracting flues and ventilating shafts, it again passes off into the outer air at a considerable height above the building. An uniformity of action is obtained by making each pair of flues used for the foul air of equal length on all the stories, and introducing fresh air into them. Each cell contains 800 cubic feet, and a ventilation is obtained of 30 cubic feet per minute, at a cost during the winter months of less than a farthing per cell, and during the summer at half that expense.

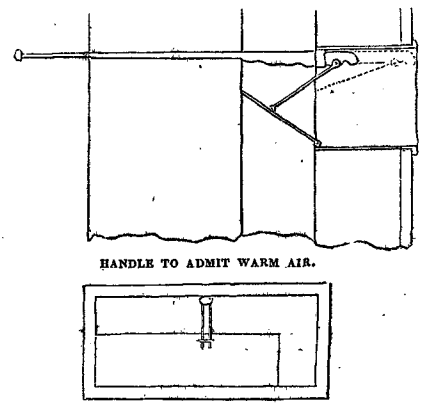


Fig. 579. REGULATORS IN THE WARM AIR FLUES.

The ascending principle of ventilation in this case extracts the foul air from the cells in consequence of the superior altitude of the shaft; had it been required to pass downwards below the floor of the cells into flues in the basement, a power must have been produced to overcome the tendency of air to rise when at a high temperature; the ventilation must then have been produced by force, instead of being as it is merely assisted. From the diffusion which takes place, it is stated that the difference of temperature at the ceiling or floor of the cell can hardly be detected, and that it seldom exceeds a degree.

The main flues in the roof, for the extraction of foul air, are connected with the vertical shaft, and during the summer a small fire is maintained at the bottom of this shaft, which raises the temperature of the column of air within it above that of the exterior, or the general temperature of the cells, and thus makes it specifically lighter. In this state it

easily rises, and the vacuum is filled from the adjoining foul air-flues, which derive their supply from the cells, the cells in return receiving a corresponding supply of fresh air to replace that which has been drawn up the vertical shaft. One hundred weight of coal per day for each wing, containing 130 cells, has been the consumption. The principle here

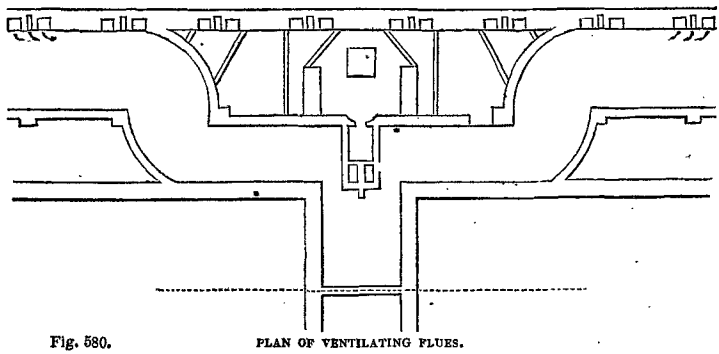


Fig. 580. PLAN OF VENTILATING FLUES.

adopted is similar to that used in deep mines, the ventilating chimney serving the purpose of the upcast shaft.

Warming is effected by an apparatus where the whole radiating surface derives its heat from the circulation of hot water, and it is calculated that the area of the whole is sufficient to maintain a temperature of 60 degrees, when the external air is at 32. There is a provision for increasing the radiating surface in the main flues as its temperature becomes lowered by an increased distance from the boiler, so that the most remote cells are equally warmed.

The apparatus consists of a double iron case; the space between being filled with water becomes the boiler; the fire is lighted in the interior, but is not brought in contact with either the sides or top: from the top of the boiler a rising main communicates with the various circulating pipes, and the return pipes are introduced at the bottom. The external case of the boiler is covered with vertical plates 7 inches deep, and $\frac{3}{8}$ of an inch thick, placed about 5 inches apart, and disposed in zigzag lines over the whole surface. The apparatus is set in brickwork, and the plates occupy the interior of the air-flue which surrounds the boiler; they are useful both as radiators and keeping the air longer in contact with it. A slide valve placed in the main flue-pipe regulates the circulation, and lowers the temperature if required. The pipes being disposed in flues formed of brick, they can only be moderately heated, and impart in consequence a genial warmth to the current of air passing through them.

The cost of erection of the Pentonville model prison was as follows: —

	£	s.	d.
Messrs. Grissell and Peto's contract, &c. for the building	70,115	14	6
Asphalte for cells, roads, and paths	2,503	8	9
Water-closets, fittings, basins, cocks, &c.	1,154	10	9
Locks, fastenings, bells, &c.	941	5	9
Superintendence	689	4	11
Sundries	361	10	9
	75,765	15	4
Additional expenses for fittings, furniture, &c., Artesian well and machinery, heating and cooking apparatus	8,402	12	2
	£84,168	12	2

Which, divided by 520, the number of cells, gives for each 161*l.* 17*s.* 2¾*d.*

Besides the prison the following are to be added: —

	£	s.	d.
Detached residence for seven families, complete	1,892	7	1
Archway and terrace wall	2,856	5	2
Wall enclosing garden	739	10	7
Stables and road	415	0	0
	£5,903	2	10

The total amounts of the several trades were as follows: —

	£	s.	d.
Excavator and bricklayer	36,140	0	4½
Carpenter and joiner	10,670	12	2
Mason	5,793	13	3¾
Plasterer	6,252	5	3¼
Painter	1,306	3	11
Glazier	1,347	12	11
Plumber	2,466	13	5
Slater	1,733	5	7
Smith and founder	9,958	4	8¾
Sundries, including the warming apparatus, &c.	754	6	0¾
	£76,423	2	9

	£	s.	d.
Items of the cost of the Artesian well, sunk 370 feet in depth, with the 30 feet cast-iron cylinders, 5 feet in diameter, pipes for bore, &c.	1,060	0	0
Building for the cranks, stages, and ladders	299	6	10¼
A three-throw pump and raising main to the top of the well only	165	2	2
Machinery	76	6	2
	£1,600	15	2¼

Major J. Jebb, of the Royal Engineers, gave the design for this model prison, and to him the country is indebted for the admirable arrangements which it contains, and for the regulations and able management which prevail within it.

BOOK II.

THEORY AND PRACTICE OF ENGINEERING.

CHAPTER I.

GEOLOGY.

Geology and Mineralogy are equally important to the civil engineer, and it is in proportion to his acquaintance with these comparatively modern sciences, that he is rendered skilful in the formation of roads, canals, harbours, mining operations, building of bridges, or forming foundations of any kind, and draining; wherever the scene of his labours may lie, he cannot be entirely successful, without a careful consideration of the various layers or strata composing the earth's crust.

When Smeaton was called upon to construct the Eddystone lighthouse, he commenced by examining the structure of the rock on which it was to be based; and as far as was possible endeavoured to imitate *nature* in his arrangement of the first and subsequent courses. Had the builders of the Leaning Tower at Pisa been equally careful, or had they been acquainted with the composition of the earth on which they laid their foundations, the world would never have had the opportunity of supposing that its inclination was the effect of design, instead of the consequence of an insecure base, which might have been consolidated by art; had the alluvial matter on which the footings are laid been converted into a mass of conglomerate or artificial rock, this famed Campanile would have stood as upright as the Eddystone lighthouse, a position which would certainly have been more in unison with the beauty of its architecture, though perhaps not so conducive to its celebrity. For all the purposes of building, it is necessary that the constructor should be acquainted with the formation and properties of the matter with which he has to deal; he should understand the cause of the durability of a substance, whatever it may be, as well as what disintegrates or destroys it.

On examining the geological structure of England, we shall find that it exhibits nearly all the variety of strata discoverable on the continent of Europe, in the same successive order; the dip, though occasionally broken, generally inclines towards the east or south-east, and in this direction is the drainage effected. It is possible that before the rocks, which make up the greater portion of our island, were deposited, the general outline was marked out or defined on the bed of the ocean, and this platform, after having been elevated by some disturbing forces, and the protrusion of igneous rocks, then received the several deposits, the succession of which with the variety of plants and animals of extinct genera, the disturbance of the several strata after their formation, sometimes by their elevation, at others by their depression, afford ample subject for consideration and enquiry; and from the talent and ability of the various geologists, who are giving free scope to their researches, and diligently observing all that is opened to their view in the several mining districts, or where any deep cutting is made, we may hope in time to obtain a clear and satisfactory solution of those phenomena which are at present involved in doubt and obscurity.

In travelling through a country the geologist knows by the strike of a stratum, or series of strata, in a range of hills, with a steep fall on one side, and a gradual rising on the other, that the latter indicates the dip; the prevailing strike being generally found to extend over the whole tract of country; and as by the inclination of the strata the drainage of the district is effected, so the various rivulets may be accounted for, and their sources ascertained.

To the miner an acquaintance with geology seems indispensible, to enable him to trace the various disruptured strata, which often baffle the observations of others. A correct estimate of the mineral veins, and the circumstances under which they have been formed, as well as their general direction, can only be ascertained by a study of this science, and a practical acquaintance with the various rocks in which they abound; but the mechanical contrivances by which the miner is to test his theories, and make them profitable, are provided by the civil engineer: both private and public interest, therefore, demand that he should be acquainted with these subjects, for if not conversant with the matter to be worked upon, it is scarcely possible that he should apply the proper means, certainly not with the requisite economy. On the coal fields, which are a most important study, we have scarcely any thing written that is practically useful, although the subject of ventilation, and the prevention of accidents in mines, has obtained much consideration

To the civil engineer the geological map, with the heights of the sections above a certain level now forming, will be of great utility, enabling him to investigate the geological features of particular districts. In many cases several portions of the same district have been examined and reported upon, and sections of the strata have been surveyed and laid down, showing the position of the beds, to a scale of 40 feet to an inch: the details are given with full investigation into their mineral deposits, and notice taken of their organic remains. The geological structure is shown in different directions, to a scale of 6 inches to the mile, with the relative heights and distances. The maps are duly verified and coloured, to exhibit the detail with the boundaries of the coal fields and districts of different formations. The agricultural character of the country is defined, and for the mining districts contour lines distinguish the dip of the various beds of rock or coal, and as the faults in a district are known, the means of ascertaining exactly where the vein is again to be met with are clearly given. These contour lines are highly useful, as they assist in affording information on the subject of drawing off the water, which, if suffered to accumulate, would put a stop to mining operations. The miner and agriculturist are interested in the completion of this general survey, which will at once attest the importance of geology to all practical men. For the supply of water, the selection of building materials or the metals, this map promises to afford a clear and useful guide, and to establish principles which will direct all operations where either the architect or engineer are employed.

The advances made of late years in geological knowledge have unquestionably produced greater certainty in all mining operations. To obtain a mineral ore deposited in veins, different means must be adopted to those required when it is in alternate beds: and it is rare to find the process the same in any two districts. In the tin and copper mines, for instance, in the west of England, the ore is drawn from fissures in the carboniferous or newer Palæozoic system, or from those cracks in igneous rocks which crop out near the surface, and such minerals are often of great value. In Sweden the ore is obtained in large lumps, and used for the manufacture of the best quality of steel; differing materially from that regularly bedded in the stratification, and constituting a part of the fossiliferous stratified rocks.

Veins usually traverse the strata in a direction by no means agreeing with, or having any reference to, their deposition; they have more the resemblance of fissures or cracks, which have been subsequently made in the rocks, and have by some mechanical means been filled up with mineral substances, which are generally, in such cases, either copper, lead, tin, or other metals, united with sulphur, carbonic acid, and other bodies, with argillaceous or siliceous substances; and such veins usually pass through the strata of rocks in a downward direction, often beyond the reach of the miner; they are also found extending horizontally, and diminishing in their course until absolutely lost. They differ in name according to the district: they are called pipe-veins when their direction is nearly parallel with the beds and the ore makes no shoots in a lode; where shoots occur, the vein dips from the neighbouring granite, which is the case whether the rock containing the ore be in itself crystalline or the effect of stratification. Shoot-veins implies a state where masses of ore occur in stratified rocks, and take an oblique direction, conformable to the dip of the beds.

Flats is another term given to those lateral extensions which are parallel to stratification, as in those veins which spread over layers of any particular rock. There are other terms expressing the condition in which the ores are met with, as that made use of in Germany, called stockwork, which indicates the working in floors one below the other.

Veins are found in a vertical position, and seldom at a greater angle than 10°, though in Cornwall they are met with occasionally at 45°; they affect the mineral character of the rocks that contain them by softening them, probably by the water, which circulates more freely around and within them. The dip or inclination of a lode is called the *slope*, and the intersection of the vein with the surface the *strike*; and in a mine the terms applied to a house are used, the floor, the roof, and the walls. The ores found in the metalliferous veins have no relation whatever to the rocks through which these run, the contents of a vein being silex, fluor spar, or carbonate of lime, which the miners call vein-stone, in which is the ore from whence the metal is extracted; and the more intelligent the geologist, the less difficulty will he have in deciding whether a vein will be productive, and deserving the labour of the miner.

Crystalline quartz, fluor spar, and carbonate of lime, contain ore in one form or another, either in small veins, or in crystalline masses, or disseminated crystals. At other times a rich ore is discovered in an earthy and powdery state; when the fissures are filled with clay or sandstone, they rarely abound with ore in a sufficient quantity to make it worth preserving. A change in the nature of the rock indicates to the miner what he is to expect for his toil, there being in most districts an order in the arrangement of the ores in veins. In the older rocks, when a vein contains copper, and it passes from a slaty formation, without altering its direction, into granite, it at first increases in richness, and afterwards gradually

diminishes. Granite is often found to yield tin ore in abundance, whilst in the same district the slate abounds with copper, lead, and tin.

In Derbyshire the lead is obtained from the carboniferous limestone and toadstone rocks, and the veins, which are valuable in the first, become poor as they pass into the other. In Cornwall copper is most abundant where the granite and kellas unite; and in Alston Moor the veins of lead are richest in the limestone, a bed of which measuring 70 feet in thickness being much more abundant than those in other districts which extend to a depth of 1000 feet, through eight varieties of limestone, eighteen of grit, and twenty-six of shale.

In a country abounding with ores, both the geologist and the miner have a guide to lead them to the veins: they are characterised by their positions and contents. In Cornwall the earliest are those of tin; they underlie to the north, and are traversed by others of a second class, and of smaller value: from these two all the tin ore is obtained; and the width of the lodes varies from that of a mere thread to 30 or 40 feet in thickness; the most productive lie east and west. The copper lodes in Cornwall also lie east and west, and traverse the tin; there are others termed *contra*, because they cross at right angles.

The Slides consist of imperfectly formed veins, and run in various directions, though the most productive are usually east and west, and the cross courses north and south.

Lead in England is found in veins running from east to west, which are traversed by cross courses at right angles to them less productive. Out of 300 observations made in Cornwall, the direction taken by most of the veins was between west and south-west or west and north-west. Mineral veins, as has been observed, are quite independent of the rock in which they are found, and differ also from them in age; being filled up long after the fissure was caused, or the disturbing force of the several strata applied. The three chief mining districts of England are found in mountainous regions: the granite rocks in Cornwall rise to an elevation of 1300 feet above the level of the sea, in which are the tin, and a considerable proportion of the copper used in commerce.

The Devonshire mica slate and granite dykes offer to the traveller a surface of country barren, and apparently unprofitable, but under it is a variety of minerals; and in Derbyshire the region around the Peak affords abundance of lead. The high moors of the north in Northumberland, Durham, and Cumberland, yield a rich return of the same ore. In the Island of Elba iron ore is obtained from veins in sedimentary rocks, which are contiguous to igneous rocks. Wherever the metals are found, their deposit seems owing to electric or magnetic influences; but the hypotheses on this subject are not at present satisfactory. After the mineral vein is found, the engineering operations commence, which must be carried on to a considerable extent before any advantages can be derived. A pit or shaft is sunk, and an horizontal gallery or tunnel driven, through which the drainage of the mine is effected, and which is called the adit level; the horizontal *drivings*, the downward *sinkings*, and the upward *risings*, are set out with reference to the locality or direction of the strike of the vein. There are usually two sets of galleries, both horizontal, at right angles to each other, one being in the direction of the strike of the vein, and the other at right angles to it, which serve the double purpose of extracting the ore and carrying off the water, which rises from the springs or drains from the several strata. The great adit or drain in Cornwall, which receives the water from the Gwennap and Redruth mines, is nearly 30 miles in length, and discharges its waters into the sea, about 40 feet above high water-mark.

When the works are extensive, many shafts are requisite, though there is usually one of greater diameter than the others, which communicates with all the horizontal galleries; this principal shaft is generally double, or divided into two compartments, one of which is devoted to the engine, which pumps the waters from the deep workings into the adit level; the other is called the whim shaft, through which the ores are drawn up. The workings of the several lodes are commonly connected by horizontal shafts, or by cross-cuts, so that their contents may be brought to the shaft and drawn up. From the extraordinary depth that many of these shafts are sunk, the greatest care is requisite; that of the Dolcoath Mine in Cornwall is upwards of 240 fathoms in depth, 210 of which are below the adit level, this being 30 below the surface. The total amount of sinking of these shafts in Cornwall has been estimated at 12 miles of perpendicular height, and the horizontal galleries as extending altogether to 40 miles in length. It is not only necessary for the engineer to direct his attention to the best method of extricating the ores, or draining off the water, but also to introduce a supply of fresh air into the workings, to lower the high temperature which is encountered at the greater depths beneath the earth's surface. This is effected by making use of the several shafts and galleries which have communication with them; the currents of air, produced by the variations of temperature, set in different directions; these by mechanical contrivances are made to keep up a constant ventilation; where gunpowder is used to blast the rocks, a considerable quantity of gas is evolved, which is injurious to the atmosphere of the mine, and therefore requires to be dissipated by ventilation, the gas which is evolved at each explosion being equal to at least five thousand times the volume of the powder made use of.

In the formation of a railroad or a canal, a vast advantage is gained by an acquaintance with the structure of the land to be operated upon. The setting out of the line depends upon the geological character of the country; and in carrying the work into execution, much labour and expense may be saved, by understanding how the various soils passed over should be worked.

The clay, which alternates with occasional sand when deeply cut, is often dangerous, and is maintained in its position with great difficulty; the water carrying away particles of sand, leaves the clay to slide down upon its slippery bed after the layer of sand is washed away. Wherever clay is cut through in the direction of its line of strike, it has a tendency to slip, which can only be avoided by draining or drawing off the water of each bed cut through, or by giving a greater inclination to the rise side of the bed than to the dip side.

Chalk offers but little difficulty, as it will stand nearly perpendicular, but it is preferable, on account of the drainage, to make the cutting through it at right angles to the strike of the beds. Where sandy or loamy earth occurs, the slope of the excavations should always be made, if possible, in conformity with the dip of the bed, and so in other loose soils.

In tunnelling the geologist is the best pioneer; he alone can point out the state of the various strata and the nature of the rock to be cut through, the probable amount of water contained by them, and the best method of draining it off.

Even in making and repairing the common highways, a scientific acquaintance with the subject will render the selection of the materials a much more secure and easy task; it too frequently occurs that no consideration is made of either the friction or pressure; it is sufficient that the ruts are filled up, whether usefully and durably is not considered.

The ordinary flint when used should be broken to a regular and moderate size; limestone forms a smooth, but not so durable a road; whinstone, where it can be obtained, is preferable to either.

In the formation of harbours, or the works which appertain to them, where the violence of the ocean is to be resisted, it is impossible, without a study of the coast, to effect anything that shall be permanent, except by experiments causing an unnecessary outlay. The geologist observes the forces by which the projecting headlands are gradually worn away, and the earthy matter deposited by the various currents, and is thus enabled to direct the best means of resisting the injuries to which most harbours are subject; and providing against their silting up, and the formation of bars or other impediments to the vessels seeking shelter.

In the selection of materials for the purposes of building, geology has been of great assistance, pointing out to us that a stone which resists the action of the air may be decomposed by water, and one that is porous and impermeable to water may be disintegrated by frost or the action of the atmosphere.

Limestones are divided into argillaceous, crystalline, and another variety, which compose the several Oolites. The Magnesian Limestones require great care when used for building purposes; they are obtained from the beds which overlie the lower new red sandstone, from which they are separated by the coal measures.

The sandstones employed in building are of various qualities, those taken from the older rocks are mostly preferred. The Craigleith is of excellent quality, of a light grey colour, and a fine grain; it contains 98 per cent. of silica, and not more than one per cent. of carbonate of lime; it is heavy, and its particles are firmly bound together; the beds are in some instances 10 feet in thickness; it is much more difficult to work than Portland stone. There are many varieties of gritstone, some where quartz grains are united with argillo-siliceous cement, but those containing iron are subject to decomposition, and they absorb upwards of a fourth part of their bulk of water. All stone should be applied in a building as it is found in the natural bed, for being usually laminated it is liable to split, if loaded or pressed in a direction opposite to the planes of deposition.

As this subject is more fully considered in the sequel, we shall proceed with some account of the different strata in the order they appear, commencing at the earth's surface, and noticing the organic bodies that are found in the several beds, for the purpose of identifying the strata. This order and arrangement belongs more immediately to the palæontologist: a brief account therefore of the various classes and orders of these organic remains will be sufficient.

Organic remains or fossils, which are found in every stratified formation, are numerous, and endless in their variety; they consist of both animal and vegetable productions, and the study of them is termed Palæontology, or a description of what had existence some ages past. The animals found are divided into the Vertebrated and Invertebrated.

The *first* form four classes, Mammalia, Birds, Reptiles, and Fishes.

The *Mammalia* are divided into nine orders; *first*, Man, or Bimana; *second*, Quadrumana; *third*, Carnivora, which is subdivided into four families, the Cheroptera, the Insectivora, the Plantigrada and Digitigrada, and the Amphibia; *fourth* order, the Marsupials; *fifth*, the

Rodentia; *sixth*, the Edentata, which have three tribes, viz. the Sloths, the ordinary Armadillo and the Ant-eater, and the Monotremata; *seventh*, the Pachydermata, which is subdivided into Proboscidiana, Pachyderms, and Solipedes; *eighth*, the Ruminants; and *ninth*, the Cetacia

The Birds or Oviparous Vertebrata are rarely found in a fossil state.

REPTILES are in great abundance and variety, and are divided into eight orders, viz. the *Dinosauria*, or land saurians; the *Enaliosaurians*, or those of the sea; *Crocodilia*; *Lacertilia*, or lizards; *Pterosauria*, or flying saurians; *Chelonia* or tortoises, &c.; *Ophidia* or serpents; and *Batrachia* or frogs.

FISHES are divided into Ganoidians, Placoidians, Ctenoidians, and Cycloidians.

The INVERTEBRATA are divided into four classes: the first is the *Mollusca*, which is subdivided into seven orders; the Cephalopoda, the Pteropoda, the Gasteropoda, the Conchifera, the Brachiopoda, the Tunicata, and the Cirrhopoda.

The *second class* is the *Articulata*, which comprises five orders, viz. the Crustaceans, the Arachnidans, the Insecta, the Myriapoda, and the Annelidans.

The *third class*, or *Radiata*, is divided into two groups; one of which has received the term Nematoneura, which is divided into five orders, viz. the Echinodermata, the Epizoa, the Rotifera, the Bryozoa, and the Cælelmintha.

The second group of Radiata is called Acrita, and comprises five orders, viz. the Sterelmintha, the Acalephæ, the Polygastrica, the Polyps, and the Sponges.

Lamarck has made another arrangement, dividing the Mollusca into two classes, Conchifera and Mollusca, and the whole into families.

The 1st family in his classification is the *Tubicolidæ*, among which is the Aspergillum, Clavagella, Teredo, &c.

The 2nd family is the *Pholadidæ*, of which is the Pholas, Gastrochæna, &c.

3rd. — *Solenidæ*, which contains the Solen, Panopæa, &c.

4th. — *Myidæ*; the Mya, Anatina.

5th. — *Mactridæ*; Mactra, Crassatella, Erycina, Lutraria, Ungulina, Solemya, Amphidesma.

6th. — *Corbulidæ*; Corbula, Pandora.

7th. — *Lithophagidæ*; Saxicava, Petricola, Venerupis.

8th. — *Nymphidæ*; Sanguinolaria, Psammobia, Tellina, Corbis, Lucina, Donax, Capsa, Crassina.

9th. — *Conchidæ*, which are fluviatile and marine; among the first are Cyclas, Cyrena, Galathea; among the latter Cyprina, Cytherea, Venus, Venericardia.

10th. — *Cardiidæ*; Cardium, Cardita, Isocardia, &c.

11th. — *Arcidæ*; Cucullæa, Arca, Pectunculus, Nucula, Trigonia, and Castalia.

12th. — *Naiidæ*; Unio, Hyria, Anodon, and Iridina.

13th. — *Chamidæ*; Dicras, Chama, Etheria.

14th. — *Tridacnidæ*; Tridacna, Hippopus.

15th. — *Mytilidæ*; Modiola, Mytilus, Pinna.

16th. — *Malleidæ*; Crenatula, Perna, Malleus, Avicula.

17th. — *Pectinidæ*; Pedum, Lima, Plagiostoma, Pecten, Plicatula, Spondylus, Podopsis.

18th. — *Ostreidæ*; Gryphæa, Ostrea, Vulsella, Placuna, Anomia.

19th. — *Rudista*; Sphærulites, Radiolites, Calceola, Birostrites, Discina, Crania.

20th. — *Brachiopoda*; Orbicula, Terebratula, Lingula, &c.

The second class are the *Mollusca*,

The first order of which are the *Pteropoda*; Hyalæa, Clio, Cleodora, Limacina, Cymbulia, Pneumodermon.

2nd Order. — *Gasteropoda*.

21st Family. — *Tritonidæ*; Glaucus, Eolis, Tritonia, Scyllæa, Tethys, Doris.

22nd. — *Phyllidida*; Phyllidida, Chitonellus, Chiton, Patella.

23rd. — *Semi-phyllididæ*; Pleurobranchus, Umbrella.

24th. — *Calyptræidæ*; Parmophorus, Emarginula, Fissurella, Pileopsis, Calyptræa, Crepidula, Ancylus.

25th. — *Bullidæ*; Bulla, Aplysia, Dolabella.

3rd Order, — *Trachilopoda*.

26th Family. — *Helicidæ*; Helix, Bulimus, Achatina.

27th. — *Limnæidæ*; Planorbis, Physa, Limnæa.

28th. — *Melanidæ*; Melania, Melanopsis, Pirena.

29th. — *Peristomidæ*; Valvata, Paludina, Ampullariæ.

30th. — *Neritidæ*; Navicella, Neretina, Nerita, Natica.

31st. — *Janthinidæ*; Janthina.

32nd. — *Macrostomidæ*; Sigaretus, Stomatella, Haliotis.

33rd. — *Plicacidæ*; Tornatella, Pyramidella.

34th. — *Scalaridæ;* Vermetus, Scalariæ, Delphinula.
35th. — *Turbinidæ;* Solarium, Rotella, Trochus, Monodonta, Turbo, Planaxis, Phasianella, Turritella.

The Zoophaga form the next section.

36th Family. — *Canalifera;* Cerithium, Pleurotoma, Turbinella, Cancellaria, Fasciolaria, Fusus, Pyrula.
37th. — *Alatæ;* Rostellaria, Pteroceras, Strombus.
38th. — *Purpurifera;* Cassis, Cassidaria.
39th. — *Columellidæ;* Columella, Mitra, Voluta, Marginella, Valvaria.
40th. — *Convolutidæ;* Ovula, Cypræa, Terebellum, Ancillaria, Oliva, Conus.

The fourth Order. — *Cephalopoda.*

41st Family. — *Orthoceratidæ;* Belemnites, Orthoceras, Nodosaria, Hippurites, Conilites.
42nd. — *Lituolitidæ;* Spirula, Spirulina, Lituola.
43rd. — *Crasticidæ;* Renulina, Cristellaria, Orbiculina.
44th. — *Spherulidæ;* Meliola, Gyrogona, Melonia.
45th. — *Radiolididæ;* Rotalia, Lenticulina, Placentula.
46th. — *Nautilidæ;* Discorbis, Siderolites, Polystomella, Vorticialis, Nummulites, Nautilus.
47th. — *Ammonitidæ;* Ammonites, Orbulites, Ammonoceras, Turrulites, Baculites.
48th. — *Argonauta.*
49th. — Genus Octopus, Laligopsis, Loligo, Sepia.

Fifth Order, *Heteropoda.*

50th Family. — Genera Carinaria, Pterotrachea, Phylliroe.

Plantæ or Fossil plants; these are either terrestrial, fluviatile, or marine: when met with in the blue clay they are often converted into jet, and sometimes their interior is changed into carbonate of lime; in these cases their structure is very distinct. In a limestone which contains silica, or in calcareous sandstone, they are often found silicified; in the coal-shales they are converted into coal; in millstone grits there are only impressions of the plants, and the space they occupied contains a brown or yellow powder.

The races of plants found in the different strata all differ; the most numerous belong to the following classes: Agamia; Cryptogamia cellulosa and vasculosa; Phanerogamia gymnospermia, monocotyledonia, and dicotyledonia.

In the Newer Tertiary or Pliocene are found Zoophyta, Infusoria, Foraminifera, Mollusca acephala, Mollusca gasteropoda, Reptilia, Mammalia, &c.

In the Middle Tertiary or Miocene, Zoophyta, Mollusca acephala, Mollusca gasteropoda, and Mollusca pteropoda.

In the Older Tertiary or Eocene are Plantæ, Zoophyta, the Mollusca, and Pisces.

In the Cretaceous system are Zoophyta, Radiata, Mollusca acephala, Mollusca brachiopoda, Mollusca cephalopoda, Pisces, and Reptilia.

In the Wealden formation are Plantæ, Crustacea, and Reptilia.

In the Oolitic system are found Plantæ, Zoophyta, Radiata, Insecta, Crustacea, Mollusca acephala, Mollusca gasteropoda, Mollusca cephalopoda, Pisces, and Reptilia.

In the Lias are Radiata, Mollusca acephala, Mollusca brachiopoda, Mollusca gasteropoda, Mollusca cephalopoda, Pisces, and Reptilia.

In the New Red Sandstone are Radiata, Mollusca acephala, Mollusca brachiopoda, Mollusca gasteropoda, Mollusca cephalopoda, and Reptilia.

In the Carboniferous system and Magnesian Limestone are Plantæ, Zoophyta, Radiata, Mollusca brachiopoda, gasteropoda, pteropoda, cephalopoda, and Pisces.

In the Devonian system and Old Red Sandstone are Zoophyta, Crustacea, Mollusca brachiopoda, gasteropoda, cephalopoda, and Pisces.

In the Silurian and Sub-silurian are Zoophyta, Crustacea, and the Mollusca brachiopoda, pteropoda, and cephalopoda.

In the British Isles we find the Pleistocene or superficial deposits, or what by some are termed Diluvium and Alluvium, to consist of gravel and other transported materials, which usually cover the regularly stratified rocks; these in fact form the upper surface of our island, and therefore the first operated upon by the civil engineer.

The Newer Tertiary or Pliocene are the Norwich or Mammaliferous Crag, and the Till of the valley of the Clyde.

The Middle Tertiary or Miocene are the Coralline and Red Crag, the Older Tertiary or Eocene, the Bagshot sand, and London clay.

The Newer Secondary Period, embraces first the Cretaceous System, which comprises the Upper Chalk with flints, the Lower Chalk without any, Marl, Upper Green Sand, Gault, and Lower Green Sand.

The Middle Secondary comprises first the Wealden formation, which contains the Weald clay, Hastings sand, and beds of Purbeck marble.

Secondly, the upper Oolitic Series, as Portland stone, Portland sand, and Kimmeridge clay.

Thirdly, the middle Oolitic, as the Upper Calc grit, Coral Rag, Lower Calc grit, Oxford clay, and Kelloway rock.

Fourthly, the lower Oolitic, or Cornbrach, Forest marble, Great Oolite, and Bradford clay, Stonesfield slate and Fuller's earth, Inferior oolite, and Calcareous sand.

Fifthly, the Liassic group of Upper lias shale and Marlstone, Lower lias shale, and Lower lias limestone.

The Older Secondary, or New Red Sandstone formation, or Triassic system, comprises the Saliferous marls, the Red sandstones, and Conglomerates.

The Newer Palæozoic period or Magnesian Limestone, or Permian System, comprises the Magnesian limestone and the Lower Red Sandstone.

The Carboniferous system, which comes also under this head, contains the Upper coal grits, Coal measures, Millstone grit, Carboniferous limestone, and Lower carboniferous shales.

The Middle Palæozoic Period, Devonian system, or Old Red Sandstone formation, includes the slate and limestones in Devonshire, as well as the Conglomerate, Cornstone, and Till stone of Herefordshire and Scotland.

The Older Palæozoic or Upper Silurian, are the Ludlow and Wenlock Series, and Upper Cambrian rocks, and the Lower Silurian or Protozoic Series, comprises the Caradoc, sandstone, and Llardillo flags, as well as the Older Cambrian fossiliferous slates.

Stratification is found to be universal in the rocks of aqueous origin which compose the earth's crust; and this character is the first to attract the attention of the geologist; it constitutes the bed of all stones, and has been formed entirely by mechanical means. It is nothing more than the deposit of the solid matter, brought down by the rivers, and spread out over the bed of the sea. The mountains and high lands are continually crumbling away, and their particles are for a time mechanically suspended in the running streams and rivers, and are thus borne away to form fresh land.

We find that the several strata, varying in thickness, are often disturbed from the horizontal position in which they were deposited by some subterraneous movement, and the materials that constitute them are usually sand, clay, limestone, and iron; the successive layers have the appearance of having been formed under water, as they are alternately sand and mud, which have been allowed to settle at regular intervals.

The *dip* of a stratum is its inclination with the horizon, and is always at right angles with the strike; the angle which the dip makes with the horizon is its amount of deviation from the level plane.

The *strike* is the direction in which a stratum lies, or the line of intersection of the plane of the bed with the horizon.

Faults are occasioned by the breaking away or settling of one portion of the earth's crust from another, and this is sometimes found to occur to the extent of several hundred feet or more.

Denudation occurs when a portion of a valley is washed away by a flood, and *Elevation* is a term given to the upheaving of a portion of the earth's crust.

Cleavage: this is perhaps best illustrated by examining slate, which is not stratified in the ordinary way, but is found to have three sorts of stratification, independent of each other, and occurring in different directions; one is the bedding, which it is often difficult to ascertain; the other is the cleavage plane; and the third is the divisional plane or joint.

Cleavage takes place easily on those argillaceous rocks where the planes are parallel to each other; and these are often found to exist without being the result of stratification; probably the cause of these masses being so divisible into planes is a partial crystallisation, for when clay moistened with acidulated water is subjected to voltaic action for some time, it will show a laminated structure, the planes of the lamina being found at right angles to the electric forces.

It is now necessary to give a description of each stratum, commencing with the

Tertiary Series, which were probably occasioned by the deposits from large rivers into estuaries, as they consist of beds of gravel, clay, sand, and friable sandstone, and were formed after the present land had become divided into bays and gulfs, or lagoons of various extent and depth; arenaceous deposits prevail; argillaceous types are found in particular districts; calcareous rocks, having a marine as well as freshwater formation, lie spread out in many basins, and marl as well as gypsum are found locally accumulated. Conglomerate containing fragments or entire boulders constitute some of the arenaceous rocks, and are of various colours, probably produced by the oxide of iron which they contain; some of these sands, which are rarely hard enough to constitute stone, are variously tinted, others are colourless; the green colour is produced by a silicate of iron.

The flints left by the destruction of the chalk, after being subjected to the action of water, occur in the state of rounded pebbles, accompanied with layers of lignite and sul-

phuret of iron and clay; the whole being subjected to long abrasion, and exposure to the oxygenating processes of the atmosphere.

The Argillaceous Sediments consist of a variety of light greenish and blue marls, with beds of gypsum, and those which are found accompanying the coloured sands of Alum Bay, in the Isle of Wight, are singular from the variety as well as richness of their tints.

The limestone is soft, marly, and generally abounds in shells. The whole of this formation was in all probability derived from the detritus of those rocks that surrounded the seas where they were deposited; or different rivers emptying themselves into the same estuary might each bring with it sedimentary matter taken up in its course, either argillaceous, calcareous, or siliceous, more or less finely comminuted. The velocity of the several streams would influence the deposits, and distribute them at several distances and depths; but in all cases the tertiary formation is the result of stratiform deposits, and the most striking features consist in the repeated alternations of marine and freshwater beds.

The marine formations of this series are divided into *Newer Pliocene, Older Pliocene, Miocene,* and *Eocene,* and alternating with these there intervenes a fourfold series of other strata, or freshwater formation.

The Newer Pliocene consists of lacustrine and fluviatile deposits, and the majority of shells found in it bears a great resemblance to those of the living species; this system in Sicily alternates with volcanic beds, and is constituted of hills, rising in some cases upwards of 2000 feet above the level of the sea; and the species of shells found in them are similar to those inhabiting the Mediterranean Sea.

The great limestone formation, which is the uppermost of these strata in Sicily, bears some resemblance to the calcaire grossier of the Paris basin, and consists of a yellowish white calcareous rock, often containing leaves of plants, reeds, &c. as if a river of fresh water with carbonate of lime in solution had floated down these vegetable remains. Its thickness is sometimes 800 feet; in some situations it is of a more compact character, and may have been precipitated from the waters of mineral springs.

The Older Pliocene. — The Norfolk Crag formation comes under this division, and resembles a raised sea beach; it is composed of layers of sand and pebbles, mixed with marine shells, and occupies much of the low ground of the eastern coast of England; the pebbles found in it are much worn and abraded, and resemble those on the margin of a sea influenced by tides. This crag is usually considered the uppermost of the British strata, and consists of several layers.

The Miocene comprises the Red and Coralline Crag, the latter being formed of calcareous sand, derived from corals in a state of decomposition, among which are embedded sponges, corals, and shells in good preservation: this formation in Suffolk is quarried and used for the purposes of building; it is not stratified, its bed does not exceed 10 or 12 feet in thickness, and it is of a soft nature. The Red Crag, which is uppermost, has a deep ferruginous colour, and is formed of layers of siliceous sand, mixed with broken shells, and was probably cotemporaneous in its formation with the coralline: among the shells are the genera Buccinum and Murex, exclusive of Polypi, Radiaria, and Crustacea; some hundreds of species of invertebrated animals are found, among which are Annulata, Cirrhipeda, Conchifera, and Mollusca. In the Suffolk Crag is the Fusus contrarius and the Fusus bulbi; and in many parts of the cliffs of Norfolk and Suffolk, sand and shingle alternate without any organic remains; whilst in others there are abundant remains of the bones of terrestrial quadrupeds, as well as Ammonites, vertebræ of Ichthyosauri, and drift wood, sometimes lying in confused masses, at other times in regular strata. From the mixture of these terrestrial and marine remains, there can be but little doubt that the crag formation was partly deposited at the mouth of a river: the bones of the mammalian remains are ascertained to belong to the leopard, the bear, the hog, and a large kind of deer; some of the Mammalia of the Norwich crag are of a more recent date, such as the teeth of the Mastodon longirostris, the elephant's tusk, the bones of the horse, the hog, and the field mouse, mixed with those of birds and fishes.

Eocene.— In this formation may be classed the Bagshot sands, which are of an ochreous colour, and are found alternating with foliated green clay, green sand, and various coloured foliated marls; a few shells are occasionally met with in the marls, of the genera Trochus, Pecten, and Crassatella; though organic remains are rare, remains of fishes do occur; the greatest elevation above the level of the sea is 465 feet.

The fresh-water formations of the Isle of Wight are divided into an upper and lower deposit, the bed separating them containing marine remains; the shells belonging to genera Murex, Buccinum, Natica, Venus, Nucula, and Corbula.

The upper fresh-water formation, composed of yellowish marl, contains shells of the genera Limnea, Planorbis, and Helix.

London Clay has either a bluish or black colour, and sometimes passes into calcareous marl, having a depth of more than 1000 feet in thickness. Argillaceous limestone containing calcareous spar occurs in numerous layers, as well as ovate or flattish masses, called

Septaria. In some localities these occur at upwards of 200 feet in depth. The shells of the Paris basin are also found in it, but there are no remains of terrestrial mammalia, although there are those of the tortoise and crocodile, which indicate the deposition to have been made at no great distance from land; many of the shells found in the clay bear a strong resemblance to the testaceous fauna of the tropics, though they cannot be identified with any species now living. The fish found in it appear to have belonged to a warm climate: among them is the sword-fish, Tetrapterus priscus, about 8 feet in length; and the saw-fish, Prestis bisulcatus, 10 feet in length, both of which were found in the Isle of Sheppey, where more than fifty other species of fish have been discovered; the nodules of calcareous stone in that island are formed into Roman cement, and the fossil Flora resemble those on the shores of the Mediterranean. The shells are the Dentalium striatum, Paludinum lenta, Crassatella sulcata, Venericardia planicosta, Conus scrabriculus, Voluta dubia, &c.

The London and Croydon Railway, during its execution, laid open a complete section of the London clay, down to its junction with the plastic clay. At New Cross the plastic clay was decomposed sandstone, with fossils, black sand, clay and sand, occupying a depth of a little more than 30 inches; then a layer of strong blue clay of 10 inches or more; then a layer of loose ferruginous sand, about 1 foot in depth; afterwards fine sand to the depth of 2 feet or more; then a stratum of flint shingle, of the same depth; on this lies the London clay, in many places more than 15 feet in depth, and above it the top yellow clay.

The cutting near to that at New Cross is nearly 80 feet, and the rails are laid on the top of the plastic clay. About three or four years ago a great movement was observed in the embankment of the western slope, which forms the inside of the curve, taken by the line of rail: the yellow clay became, from the great fall of rain, in a semi-fluid state, and was in motion throughout its whole thickness; in a few hours more than 50,000 cubic yards slipped on the surface of the blue clay, and covered the rails for a considerable distance. The blue clay is stiff and insoluble, and so compact that it is impervious to water; but the yellow clay above is mixed with a variety of other matter soluble in water, as lime, fullers' earth, and bands of septaria; these being dissolved occasioned faults and fissures within, which became filled with water, caused an expansion of the mass, and at last its falling down, from not being able to sustain its own weight on the steep slopes at which it had been cut. The strata also dipped in a manner to favour the slipping, which chemical action may have aided, for the iron pyrites found in the yellow clay may have been decomposed by exposure to the atmosphere, and sulphuric acid evolved, which, entering into combination with the carbonate of lime, would form crystals of silenite, materially affecting the bulk of the whole mass, and assisting the separation of the clay.

To remove this slip stages were erected at each end, sufficiently high to permit the waggons to run under them, and advance gradually into the slip, a way being cut by working a gullet down to the rails. Two sets of waggons were made use of, which, when filled, were drawn away by locomotives to the nearest embankment, where the contents were either carted or wheeled to their destination. When the whole was cleared, a cutting was commenced at each side where the slips took place, and after removing above 250,000 cubic yards of clay, the slopes were trimmed back to what was considered a safe inclination. This was effected by cutting benches and intermediate slopes; on the west side there are three benches, and on the other two; these benches vary in dimensions up to 65 feet in breadth, and the several slopes are cut with an inclination of 2 to 1. Drains are formed both on the benches and in the slopes, to carry off the surface water.

Some of the earth on this line is very untractable: at Forest Hill a continued rain resolved it into mud; and after all attempts to drain it were found ineffectual, a bench 70 feet in width was cleared about 20 feet up the slope, and on this 100,000 cubic yards of clay were run; at the back of the benching was a retaining wall of gravel, nearly double its width, and varying from 5 to 12 feet in height; the clay taken out was then thrown in front of it, to gain additional weight, and a greater firmness in the soil has been the result. Drains of gravel seem to be in most cases efficacious, the water, which is the general cause of all slips, being by this means entirely drained off; care is also required to secure the foot, and to make the slopes in such soils from 3 and 4 to 1.

Retaining walls on the London and Birmingham line, near the Euston Square station, were forced inwards from the expansion of the clay behind them: they were of brick, 5 feet 6 inches thick at bottom, and 2 feet 6 inches at top, with a curved face, and whenever taken down for the purpose of repairs, the face of the clay appeared to stand perfectly straight, the expansion and the force obtained by it being attributable to the action of the atmosphere, which causes a constant contraction and expansion, if the clay be exposed even for a few hours; it is from the same influence that the sides of wells sunk in it so frequently give way; when dried, it occupies a seventh or eighth less space than when in its bed. During the heat of summer it will shrink, and form cracks or fissures, which, when the rain falls, become filled with water, the hydrostatic action of which occasion masses to break off

and slip. This water should, therefore, be collected as much as possible at the surface, and carried away by drains.

Clay in a moist situation requires a slope of at least 3 to 1, to enable it to stand; when kept dry, 2 to 1 has been found sufficient. Where sleepers have been laid upon it in mines or at the bottom of tunnels, they frequently rise up, and are broken, by the mere expansion of the clay; this occurred in the tunnel of the Manchester and Bolton railway. Houses or buildings of any kind placed upon it are in constant motion: when the weather is dry, the foundations contract, when wet expand, so that the walls are never at rest; when the clay is moist, a heavy wall will sink, and continue to do so until out of the influences that produce these changes.

Whenever a slope is made at the side of a cutting in clay it is advisable to have at the toe a footing of concrete or a wall built up to guard against the mass sliding from it. The difference in the colour of the yellow clay and the blue beneath arises from the iron they contain. When this is excluded from the air, it is found as a protoxide; in the upper clay it is a peroxide.

The London clay is more or less pervious, abounding with fissures in all directions, many of which hold a slimy earth and abundance of water: this often passes down to the lower stratum on which it rests, which, if composed of sand, is washed away, and then the whole superincumbent mass either settles or moves forward; it is supposed to contain 10 per cent. of water. Where canals have been cut through clay, and the embankments formed of the material thrown out, they have remained firm as long as their weight balanced the upward tendency of the water in the substratum of the bed of the canal; but when the increased weight of the mass destroyed that equilibrium, the embankments sunk, and forced the bottom upwards. The greatest depth of the London clay is estimated at 700 feet, and its greatest elevation above the sea at 760 feet.

Plastic clay belongs to this formation, and is of various colours; it is so called from its being used in the potteries; it is found in different degrees of thickness, and contains lignites, amber, and shells, both freshwater and marine. The number of tertiary fossils is considerable; the greater proportion are terrestrial; the fishes are so nearly related to existing forms that it is difficult to class them, crocodiles and snakes agreeing with those met with at the present day.

Upper Secondary. Cretaceous.

Upper Chalk had its surface furrowed by the action of the waves and currents before any of the sands or clays were deposited upon it, deep indentations being frequently observed, in which are imbedded sand, gravel, and flint.

The stratification of chalk is often obscure, where layers of flint are wanting; where they occur they form strata of from 4 to 7 or 8 inches in thickness, and the distance between these beds varies from 2 to many feet.

Lower Chalk is harder and less white than the upper, and is sometimes varied by green grains, generally with fewer flints, and often without any. The organic remains of the cretaceous system are nearly all marine; the plants are few, and exclusively marine, with the exception of fragments of coniferous trees, which have evidently floated in the sea, as some specimens have been perforated by Teredines.

Among the fossil shells are the Terebratulæ, which live in deep and tranquil seas, and the extinct species of Crania and Catillus, the Belemnite, Ammonite, Baculite, and Turrilite, of the family Cephalopoda, which resemble the cuttle-fish. Sea Urchins, Corals, Sponges, &c., are also dispersed through the chalk and flint; the latter of which owe their irregular shape to the inclosed zoophytes, as the hollows on their outer face are caused by branches of a sponge, which may be sometimes discovered by breaking the flint.

Fish and Crustacea are found, but no bones of land animals, terrestrial or fluvial shells, plants, sand, or pebbles, indicating a formation in a deep sea at a great distance from land. Fossil fishes, with the air-bladder distended, have been discovered in the Sussex chalk, leading to the conclusion that their destruction and envelopement were sudden.

The chalk formation in England is of great extent; it is chiefly of carbonate of lime in a fine granular state; the greatest height which it attains above the level of the sea is about 1000 feet.

Greensand generally forms the base of the chalk hills, and consists of small grains of silicate of iron agreeing in composition with chlorite; the greensand deposits are a succession of ordinary beds of sand, clay, marl, and impure sandstone, probably the detritus of former rocks, the nature of which may be traced in the pebbles of quartz, quartzose sandstone, jasper, flinty slate, and grains of chlorite and mica.

The upper greensand is a formation of sand and loam, frequently mixed with chert, which passes downward into clay and marl called *Gault*. Below the gault is the lower greensand, which is partly ferruginous sand and sandstone, with some limestone; among the latter may be mentioned the Kentish rag, used for building and repairing the roads, and among the sandstones that called firestone, which derives its green hue from grains of silicate of iron.

The fossils of the greensand are marine; among them is the Pecten quinquecostatus, several forms of the Cephalopoda, as the Hamite, Scaphite, and others, which distinguish this formation from the chalk. A specimen of a Saurian named the Iguanodon Mantelli was discovered at Maidstone.

OOLITIC SYSTEM.—*Wealden formation* is almost peculiar to the counties of Kent, Sussex, and the Isle of Wight; it is a local freshwater or estuary deposit, composed of coloured sands and clays, with lignites, conglomerates, and calcareous masses, interspersed throughout the sands, limestone and ironstone in the clay. It is divided into four several groups, viz.:—

The uppermost or weald clay is blue and stiff, with Septaria, argillaceous iron-stone, and beds of shelly limestone, called Sussex or Petworth marble (fossil Cyprides). These beds of limestone are made up of a few species of the univalve called Paludina, a fresh-water snail, common in rivers and lakes; the shells are sometimes decomposed, and their casts alone remain, the interstices being filled up with indurated marl, or calcareous concretions. In the coarser varieties are cavities left by the decomposition of the shells; in the more compact masses a crystalline calcareous infiltration of various colours has permeated the mass, and given it a beauty equal to foreign marble. There are a few bivalves traceable in this limestone, though some blocks containing large specimens (Unio) interspersed with univalves, and fragments of reptiles, bones, &c. of various tints of green, blue, grey, &c. have been found in Western Sussex. The Petworth and Bethersden stone or marble are extensions of the same bed. These marbles were most extensively employed during the middle ages for tombstones, altars, fonts, monuments, and the decorative portions of churches and cathedrals. Columns of it, highly polished, are distinguishable features in the early Pointed architecture.

Secondly.—The Hastings sand, which consists of irregular alternations of sand and sandstone, sometimes calcareous, of a grey, yellowish, or ferruginous colour, with concretions of ironstone and layers of lignite, the sandstone often having a conglomerate form, and containing pebbles of quartz and jasper.

Thirdly.—The Ashburnham beds, clays, shales, bluish grey limestones and sandstones.

Fourthly.—The Purbeck beds, clay, sandstone, and shelly limestones, with layers of vegetable mould, and remains of trees in a vertical position. The Purbeck is found in the deep valleys of eastern Sussex, but emerges on the Dorsetshire coast, and from the northern brow of the Isle of Portland. The Isle of Purbeck is an irregular oval, 7 miles in breadth, and 12 miles in length; on the eastern promontory the chalk is in a vertical position, and beds of sandstone and limestone are seen underlying this displaced strata; towards the southern extremity of the island appears the Portland limestone. The Purbeck beds are a sort of calcareous marble, of various thickness, and of a mottled colour; they abound in organic remains, the chief of which is a congeries of the shell Paludina, intermixed with minute crustaceous coverings of a species of Cypris; this marble bears a high polish; it is finer grained than the Petworth, and was much used in the decorative portions of Salisbury and Wells Cathedrals; it has unfortunately been generally placed in a contrary position to its true bed, which accounts for the long slender columns into which it was converted flaking off and crumbling away. The fossils found in the Wealden formation are exclusively of a genera either fluviatile or lacustrine, such as Melanopoca, Paludina, Neritina, Cyclas, Unio, and others; these occur in such quantities that the surface of each layer of marl is sometimes entirely covered with the valves of Cyclas, and beds of limestone are composed solely of Paludina.

The species of Bulla, that of an Oyster and Exogyra, which are met with, indicate the occasional presence of salt water. The fishes of the Wealden belong to the genera Pycnodus and Hybodus, as well as a species of Lepidotus; the general form of the latter resembles the carp, although of a distinct kind, and somewhat allied to the pike.

Among the vertebrated animals the reptiles are the most numerous, such as the Trionyx and Emys genera, found at the present day in the fresh-water of tropical regions. Of Saurians there are five genera, the Crocodile, Plesiosaurus, Megalosaurus, Iguanodon, and the Hylæosaurus. The Iguanodon, which was herbivorous, had its teeth formed like the modern Iguanas, found in America and the West Indies; its entire length has been computed at 70 feet. No skeleton of a mammiferous quadruped has been discovered: the birds belong to the order Grallæ. Of vegetable remains there are numerous varieties, all having the character of tropical productions; their resemblance to the living genera of Cycas, Zamia, and Esquesata, is very great; there are specimens of Coniferæ allied to the Araucaria, as well as many varieties of tropical ferns.

Upper Oolite. Portland Oolite.—This is a marine formation, or limestone, abounding in Ammonites, Trigoniæ, and other exuviæ: it occurs immediately below the Purbeck bed, from which it is separated by a vegetable soil, called the dirt-bed, of from 12 to 18 inches in thickness, containing a large portion of earthy lignite, with rounded pebbles or gravel interspersed. Trunks of trees, nearly allied to the Zamias and Cycas, are also buried in it, and there is every evidence that when these were growing the Portland beds

were in a softer state than they are now found, many of the roots having penetrated, leaving cavities resembling them in shape. In all probability the Oolitic beds which were formed in the sea first became dry land, were then covered by a forest, and afterwards submerged beneath a body of fresh water, from the sediment of which fluviatile shells were deposited.

The cap of the Portland Oolite is light-coloured, and of a fine grain, but shattered and full of fissures, which occasions it to fall into masses too small for any useful purpose, although it is not destitute of hardness.

The skull cap is compact and open in its texture, hard, and its grain well cemented together; it is useful for structures where ornament is not required. The Roche of both the top and bottom beds forms a portion of the stone with which it is in contact, and resembles it in its composition. The best beds are those called the top, which are situated about midway between the top and bottom of the quarry. Their thickness varies from 5 to 7 feet, although occasionally blocks of much greater dimensions are obtained. The bottom bed averages about 6 feet in depth, but the particles are not so well cemented together. They are in a loose state of combination; it is, however, often preferred, from the facility with which it may be worked, and from its fine grain.

Kimmeridge clay is of a blue colour, and consists in a great part of bituminous shale, sometimes forming an impure coal, several hundred feet in thickness, whilst in others it resembles peat. The impressions of plants are rarely found in it, but Ammonites, Ostrea deltoida, Gryphæa virgula, are mixed with the shale, and the bitumen it contains may be attributable to their animal origin.

Middle Oolite. — Upper Calcareous grit is a deposite full of comminuted shells, having an oblique lamination; it is a freestone of rather close texture.

Coral rag, or Coralline Oolite consists of two beds of calcareous sand separated by another of limestone; the lowest is of a yellowish colour, and contains about thirty per cent. of calcareous matter. The limestone is almost wholly composed of corals. The upper arenaceous deposit is close in its texture, full of comminuted shells, forming a calcareous freestone, which is useful for many purposes. Among the organic remains are the Ammonites vertebralis, Plagiostoma rigidum, Clypeus dimidiatus, Cidaris florigemma, Astrea tabulifera, and Caryophylla annulata, and frequently masses of coral as they were formed in the sea.

Lower calcareous grit is a yellowish quartzose sand, containing a considerable quantity of calcareous matter.

Oxford clay is an argillaceous deposit of a dark blue colour, which, when exposed to the action of the air, becomes brown; it contains Septaria, and concretions of argillaceous limestone separated by veins of calcareous spar; among the organic remains is the Gryphæa dilatata.

Kelloway rock is a calcareous sandstone abounding in fossils, among which is the Ammonites calloviensis.

Lower Oolite. —500 feet in thickness in the neighbourhood of Bath.

Cornbrash limestone is a coarse and impure limestone, though it has considerable hardness, and is of a compact nature. It has sometimes a crystalline appearance, and contains many shells, &c.

Forest marble is found associated with clay and sand; it is limestone of a bluish tint, with particles of oolite occurring in thin beds. In Wichwood Forest in Oxfordshire, it becomes a coarse kind of marble, which is worked for inferior purposes.

Bath Oolite occurs in beds of from 100 to 200 feet in thickness, and is calcareous; when freed from fossils it is easily sawn and worked with the chisel; it contains various corals, as the Eunomia radiata, several of which have been found of great dimensions, indicating a growth of many centuries, as the large brain coral, the *Meandrina*. The stone lilies (Crinoideans) are also common. The upper surface of the Bath or Great Oolite once abounded with a forest of these beautiful zoophytes; and there is every appearance that the deep marine waters in which they were produced were invaded by deposites of mud, which threw down and destroyed them; the stumps of some are found in their original position. Among the other fossils are the Trigonia gibbosa, Ostrea Marshii, Orbicula reflexa, Ammonites striatulus, &c.

Stonesfield slate is remarkable for its marine and terrestrial remains: it is calcareous, and consists of two beds of thinly laminated oolitic limestone, of about 2 feet in thickness, separated by calcareous limestone; it has the quality of splitting or separating into plates when struck with a mallet; after being exposed during a winter it is occasionally used for roofing. It is obtained from the quarries by driving a gallery into the side of the hill, about 6 feet in height, and as it is exhausted the sandstone is piled or built up to support the superincumbent earth. The Stonesfield slate is rich in organic remains, containing Belemnites, Trigoniæ, and other marine shells, many impressions of ferns, Cycadeæ, and other terrestrial plants, several insects, and many genera of reptiles, as the Plesiosaurus, Crocodile, and Pterodactyl, and the jaws of two mammiferous quadrupeds allied to the Opossum (Didelphys).

Fullers' earth beds are deposites of calcareo-argillaceous beds, mixed with frequent courses of soft rubble-stone, containing a considerable proportion of calcareous matter. Blue and yellow clays, called fullers' earth, are found with them; these clays are of a blue colour, changing near the surface to yellow; they are often laminated, but generally resemble a mass of argillaceous sediment, divided by laminæ of shelly limestone or lines of Septaria; pyrites and jet lie in many of them; from these clays the transition to either sandstone or limestone is usually very gentle.

Inferior Oolite possesses a brown tinge or colour from the oxide of iron it contains, which is also mixed with much siliceous matter; it sometimes passes into a ferruginous sandstone, as in Northamptonshire and the adjoining counties. The arenaceous deposites of this system are not found to be micaceous or felspathic, as those of an earlier date: a yellow tint is the prevailing one, sometimes of a deep colour; the grain is usually fine, and quartz pebbles occur as well as portions of carbonate of lime.

Sandstone, which is the lowest portion of the oolitic system, is always stratified, though often coarse-grained, and exhibiting an oblique lamination, the finer sorts splitting easily into flags or slates. Shells, and plates of oxide or carbonate of iron, are found in them, which appear the result of molecular arrangement round nuclei of other matters which have served as centres of attraction.

LIAS FORMATION is usually found stratified in conformity with the rocks of the oolitic group; it is of considerable thickness, varying from 500 to 1000 feet, and of an uniform lithological character. It is of marine origin, and consists of an alternation of thin beds of limestone, with a light brown weathered surface, separated by dark-coloured, narrow, argillaceous partings, having a striped appearance; its prevailing colour is blue, though some beds, called White Lias, have a yellowish-white tint. The organic remains are principally marine or littoral. Among the shells are the Gryphæa, Cephalopoda, Ammonite, Belemnite, and Nautilus; the fossil fish are the Lepidotus, &c.; of the reptiles there are several species of Ichthyosaurus and Plesiosaurus, and among the plants of Zamias and Coniferæ.

Upper Lias shales.—*Marlstone, Lower Lias shale, Lias Limestone*, and *Lower Lias Marls*, are its subdivisions.

POIKILITIC *or New Red Sandstone* formation is a great mass of arenaceous and argillaceous deposit, immediately below the blue lias; gypseous and rock salt, with some organic remains, are contained in it. The rocks are generally granular, of a yellow colour, and sandy nature, but not micaceous; some of them are a coarse breccia, containing fragments of limestone; others are conglomerates of various pebbles; many a coarse red grit, used for building; the grains of this red sandstone consist mostly of clear quartz, the exterior coated with red oxide of iron.

Variegated Marls are red, blue, green, or white; they are laminated, contain gypsum and rock salt; white and grey sandstones of a peculiar character are occasionally found among these marls.

Variegated Sandstone, so named from the white and mottled partitions contained in them; the lower part is a quartzose conglomerate.

The red sandstones and red marls, which form so considerable a thickness in England, are perhaps the result of the disintegration of various crystalline or metamorphic schists, and often of porphyritic trap rock, containing much oxide of iron; the red colouring matter with which this alluvium is tinted may have been furnished by the decomposition of hornblende or mica, which contains oxide of iron in large quantities. Fossil remains are rarely found in any stratified rocks where this oxide of iron abounds.

Magnesian Limestones vary in their character, and are sometimes loaded with magnesia, having either a white, yellow, grey, or smoky colour, occasionally red. The texture is compact, and sometimes oolitic, the cells being lined with crystallised carbonate of lime. Some of these limestones have a fine sandy grain, others are quite powdery, containing crystallised balls. Plates and strings of spar are very common in them, and it is this peculiarity which causes magnesian limestone, when used in building, to decay, the stone perishing between the ribs of spar, and crumbling away. The fine-grained limestone of Knottingley are thin-bedded, or flag-like, and it is often difficult to trace the beds in the powdery magnesian rocks; they are frequently traversed by vertical divisions from top to bottom, which are in some places filled with pebbles or clay.

Marl slates are laminated impure calcareous rocks, of a soft argillaceous or sandy nature.

Lower Red Sandstone, with red and purple marls and micaceous beds; the grits are white or yellow, and either of a pebbly or sandy nature. The repetition of clay, sandstone, and oolitic limestone, shows the new conditions imposed upon the land and sea, and the loose grits that the deposits were made at no great distance from land.

The red sandstone appears to have accumulated in a situation unfavourable to either the reception of vegetable or animal exuviæ.

The magnesian limestone and red sandstone are variously tinted with oxide of iron, the

clays with green or blue by the protoxide; and these colours are supposed to be the result of volcanic influence on the particles which formed the first deposits at the bottom of the ocean. The limestone is found of various densities, arising from the degree of consolidation to which its particles have been subjected. Some claim a corallaginous origin, and have their particles in different degrees of aggregation. The globular concretions of others may be owing to the submarine springs yielding carbonate of lime, mingled with magnesia, which after deposition were consolidated.

The origin of the gypsum and rock salt have been variously accounted for, and from the absence of all marine exuviæ, it does not seem to have been deposited by the sea under ordinary circumstances.

The fossils belonging to the saliferous or Poikilitic system are in Britain confined to about 50 species, the great proportion of which belong to the magnesian limestone, and contain fishes, zoophytes, and mollusca; in the lower red sandstone are many plants, and in the marls marine shells.

Carboniferous System.—Arenaceous, argillaceous, and calcareous rocks, associated with beds of chert, ironstone, and coal, are the six substances which compose it: it is of great thickness, and exhibits throughout proofs of slow and successive deposits.

Coal Measures, or the upper part of the carboniferous system, consists of alternations of argillaceous and arenaceous strata, with beds of coal and ironstone, the latter yielding 30 per cent. of iron; the sandstones are micaceous, and both coarse and fine-grained, alternating with shale. The coal is often found in 50 seams or beds, varying in thickness from 1 inch to 6 feet or more. The rocks with which it is associated are of various colours, and there is almost every possible gradation between the sandstones and argillaceous deposits; the latter being laminated are called plate or bass; when the lamination is less perfect, shale; and when quite unobservable it takes the name of clunch, bend, or some other peculiar to the locality; they are all more or less bituminous, and of a dark colour.

The limestones are compact, oolitic, or granularly crystallised, and mostly formed of pure carbonate of lime, except the granular varieties, which contain magnesia. The whole are of marine origin, though there are some exceptions. All are, however, the result of aqueous deposition, as lamination occurs throughout the whole of the six substances which compose this system.

Coal is of vegetable origin, which has been most satisfactorily proved by a microscopic examination of many varieties, after cutting them into thin plates. Impressions of plants and trunks of trees are frequently met with in the sandstone and shale; leaves, branches, and fruits occur in the nodules of clay ironstone, the vegetable itself having served as the nucleus round which the carbonate of iron has concreted.

The latest of the carboniferous deposits is said to be that in the neighbourhood of Shrewsbury, which was of freshwater origin: it consists of shales and sandstones, about 150 feet in thickness, with coal and traces of plants, including a bed of limestone of from 2 to 9 feet in thickness, of a cellular texture. The fossils contained in it are small bivalves, having the form of Cyclas, a small Cypris, and the Microconchus of an extinct genus.

In the lower coal measures of Colebrook Dale the strata often change materially within very short distances; beds of sandstone passing horizontally into clay, and clay into sandstone; the strata are from 700 to 800 feet in thickness, and more than 50 terrestrial plants have been found, besides various fishes and Trilobites, as well as 40 species of Mollusca, among which are two or three of the freshwater genus Unio, and others of marine forms, as the Nautilus, Orthoceras, Sperifer, and Productus, from whence it is inferred that these deposits were made in a bay of the sea or estuary, into which some large river poured its flood.

In the South of England the carboniferous strata consists of three formations, viz.—

Coal formation, a mass of more than 1000 yards in thickness, composed of alternations of shales and sandstones of various kinds, with about 50 feet of coal in beds, a portion of ironstone, and sometimes thin layers of limestone.

Mountain Limestone, formed of calcareous rocks, with few partings of argillaceous matter, and with few grits, no coal, some chert nodules, and occasionally layers of red oxide of iron; the whole from 500 to 1500 feet in thickness.

Old Red Sandstone, composed of arenaceous rocks, from 500 to 10,000 feet in thickness, contains some conglomerates of extreme coarseness, and sandstones of many kinds: among the argillaceous beds is concretionary limestone irregularly developed. In the North of England this triple system is somewhat modified, and consists of the millstone grit group, composed of quartzose and felspathic gritstones, and some bad coal, with shales and sandstones.

Limestone shale formed of a series of laminated shales or plates, mostly bituminous, with some ironstone, and thin black limestone, but no coal; the thickness is 1000 feet or more.

Mountain Limestone formation, where the old red sandstone is almost absent; some millstone grit and limestone shale are found about the South Wales coal-field. In the north-

western part of Yorkshire the series is still more varied and complicated. After the coal formation we have the millstone grit, or series of grit-stones, separated by shales, and several other flaggy and freestone grits, cherts, thin limestone, ironstone, and several coal-seams, 1000 feet in thickness.

Yoredale rocks are a series of five or more limestones, with many freestones, flagstones, abundance of plates, some ironstone, chert, and several coal seams, 1000 feet in thickness.

Scar Limestone, divided by grits and slates, with some beds of coal 800 feet in thickness.

Alternations of Red Sandstone, clay, and limestone, 100 feet red sandstones, and conglomerates, very limited in their range and of variable thickness.

Pursuing this system in Northumberland, we find the scar limestone interfered with by the interposition of various grits and abundance of coal. The usual thickness of coal in England and Scotland is about 50 or 60 feet, divided into 20 or more beds, alternating with from 20 to 50 or 100 times as great a quantity of sandstones and shales. Though in some districts the coal is deposited in beds above one another, with but little earthy matter intervening, in which the different beds are traceable, and possessing various qualities, probably arising from the differences of the vegetable matter that comprise them, and the manner in which the accumulation has taken place.

In the coal tracts of the Tyne and Wear there is very little limestone; in Yorkshire the total thickness of the coal formation is from 1000 to 1500 yards; in Lancashire a greater thickness, whilst in South Staffordshire it does not exceed 1000 feet. The most variable are the sandstones and shales, the most regular the coal beds and ironstones.

The organic remains in the coal formation consist of many varieties of plants in fine preservation; abundance of zoophytes, mollusca, crustacea, many fishes, but, as far as has yet been ascertained, neither reptiles, birds, nor mammalia. Many of the plants are of terrestrial growth, whilst all the zoophytes, nearly all the mollusca, crustacea, and fishes are of marine origin. The plants are somewhat similar to existing species, as the large group of ferns, though others are quite dissimilar, as in the furrowed stem of the Sigillaria, &c. &c.

The following may be taken as a brief summary of the plants:—

Cryptogamia vasculosa - -	Equisetaceæ -	20 species.
	Silices - -	100
	Lycopodiaceæ -	60
Phanerogamia monocotyledoniæ -	- - -	10
	Coniferæ - -	10
	Cachaceæ - -	50
	Undetermined -	50
		300 species.

The remains of these plants usually compose the coal seams, and one cause of the difference among them is the various structural composition of the plants themselves, which are generally confined to arenaceous or argillaceous deposits; they abound in the upper part of the carboniferous system, and they also occur in the midst of the millstone grit, in the sandstones and shales, and also among limestones, where coal-beds are found, but they are rare, or almost wholly unknown, in the midst of the undivided limestone, and in the old red sandstone. Among the Zoophytes are 40 species of the Polyparia, 40 of the Crinoidea, and 3 of the Eschenida. The Mollusca consist of 326 species, among which are of the Conchifera 40 species of the Plagymyona, 28 of the Mesomyona, 100 of the Brachopoda; Gasteropoda 92 species; Cephalopoda monothalamia 10, and Cephalopoda polythalamia 69, 10 species of which are of estuary formation, and about 60 per cent. belong to species of extinct genera.

The fishes of the carboniferous system are mostly of the Ganoid division, and both the plants and animals are very distinct from existing types.

Carboniferous and Mountain Limestone lies beneath the coal measures, and sometimes alternates with the shales and sandstones of the coal; it is destitute of land plants, and usually abounds with corals of large size, several of which belong to the lamelliferous class, which enter largely into the structure of coral reefs: there are many Crinoides, Echinides, &c., associated with the Zoophytes. Among the Mollusca are Brachiopoda, several of which are referrible to the Spirifera and Productæ; Univalve and Bivalve shells, such as Turritella, Buccinum, Patella, Isocardia, Nucula and Pecten, abound; but the Cephalopoda differ widely from living genera.

The Carboniferous limestone has a sub-crystalline texture, and some of the varieties take a fine polish, their surfaces being ornamented by the sections of inclosed Crinoidea, corals and shells; the prevailing colour is a bluish grey, the organic remains being of a pure white, but some varieties have a ground of red, others nearly black, the shells which are embedded being of a deep ochreous colour.

The Derbyshire marbles and those of St. Vincent's rocks are among the finest examples of mountain limestone; in Gloucestershire, Somersetshire, Shropshire, Derbyshire, and

North and South Wales, it is a calcareous mass, interposed between the old red sandstone, or where this is wanting, the more ancient slate rock below, and the sandstones and shales of the coal above. The Derbyshire or Encrinital marble is formed of crinoideal remains, composed of stems and detached ossicula of one species of Encrinite.

It is in the mountain limestone that the principal lead mines are situated; in Derbyshire the metal occurs in numerous veins which traverse the rock, and extend in some instances into the ancient volcanic bed. The perpendicular or rake veins are from 2 to 40 feet wide, and others are chasms or hollows in the rocks, several hundred feet wide, which also contain metallic ores and spar; manganese, iron, copper, zinc, &c., are also found, but that which most predominates is galena, or the sulphuret of lead; it is accompanied with fluor and calcareous spar, sulphate and carbonate of barytes, iron pyrites, &c. &c.

Millstone Grit is a siliceous conglomerate, or quartzose sandstone, and is composed of the detritus of the primary rocks. Fragments of granite, from the size of a pea to a large pebble, are cemented together by a crystalline paste.

Old Red Sandstone: this is of enormous thickness, and has been stated at 10,000 feet; it consists of many varieties and alternations of tile, stone, limestone, marl, conglomerates, shales, and sandstones; the latter of various states of induration, which, when schistose, are employed for roofing. The conglomerates contain abundance of quartz pebbles; the red colour predominates in the cementing material and the marls, and is derived from the peroxide of iron. The formation of the stratas has evidently resulted from the waste and degradation of the ancient slate rocks, the detritus being cemented together by red sand or marl into coarse conglomerates.

Among the organic remains are ancient forms of the Terebratulæ, Spiriferæ, Productæ, &c.; Nautili, Ammonites, and Orthocoralite, &c; Fishes, Fuci, &c.; some of the fishes belong to the genus Cephalaspis and Onchus.

Among the tile-stones the Ichthyodorulites of the genus Onchus has been found, and a species of Dipterus, with Mollusca of the genera Avicula, Area, Cucullæa, Terebratulæ, Lingula, Turbo, Trochus, Turritella, Bellerophon, Orthoceras, and others.

Upper Silurian is chiefly found in Shropshire, Radnorshire, and Herefordshire, particularly at Wooltrope.

Upper Ludlow Rocks are formed of a grey thin bedded limestone, slightly micaceous.

The Aymestry Limestone is sub-crystalline, and either a grey or blue argillaceous limestone, highly fossiliferous; among the most numerous of the fossils is a species of Brachopoda, viz. the Terebratula navicula.

Lower Ludlow Rocks are composed of sandy shales and flags, with concretions of earthy limestone. The organic remains found in them are Corals, Terebratula leptena or producta, Orthis, Pentamerius Knightii, Lingula, Orbicula, Bellerophon, &c. &c.

Wenlock Formation. — The limestone of this formation is of a grey and blue colour, highly concretionary and subcrystalline. The shale is argillaceous, of a dark liver colour, with nodules of earthy limestone, and sometimes micaceous. The organic remains are chiefly of the lower order of marine animals, as Corals and Crinoidea, among which are Producta depressa, Spirifera lineata, Euomphilus rugosus, Orthoceras annulatum, Consularia quadrisulcata, Calymene Blumenbachii, (variolata, Asaphus caudatus).

Lower Silurian.—*Caradoc Flags* are thin-bedded impure shelly limestones, finely laminated, slightly micaceous greenish sandstone.

The Sandstone is thick-bedded, and a freestone of various colours, as white, red, green, and purple. The grits are quartzose and conglomerate, the limestones sandy and gritty. Among the fossils are a few Crinoidea, Pentameris levis, Orthis, Terebratula, Leptæna, Nucula, &c.

Llandillo Flags are dark-coloured, and chiefly calcareous, with some sandstone and schist; the fossils are several varieties of Trilobites, Asaphus Buchii, &c.

The Silurian system is composed of sedimentary deposits, which are either calcareous, arenaceous, or argillaceous; the latter rocks are less indurated and less complicated in their joints of cleavage, retaining in many places their original lamination. The arenaceous rocks take the character of ordinary sandstone and conglomerate, and the calcareous are only partly crystalline. The whole of these rocks seem to have accumulated in a regular and tranquil manner, as they all show the laminæ of their deposition: in the sandstone the beds are distinctly marked; in the limestones are evidences of regular stratification, though nodular and concave on their surfaces, and sometimes partially lenticular, indicating that their origin may have been similar to that of the coral reefs.

The joints and fissures which occur in the Silurian system are usually at right angles with the planes of stratification; the organic remains are only those of Invertebrata, 500 or 600 species of shells, and 14 or 15 species of plants; each of the four formations of this system contains distinct and characteristic species of fossils.

Cambrian System. —*Upper Cambrian, or Plynlymmon Rocks.*—In Cumberland they are formed of a dark limestone, containing corals and shells; in Wales of beds of conglomerate, greywacke and greywacke slate, &c. The green slates and porphyries rest upon

the Skiddaw rock, and for the most part contain crystals of chiastolite and hornblende, without any fossils.

Lower Cambrian consists of slates of various colours, with their cleavage at right angles to their stratification; they are found with conglomerates, porphyry, and greenstone, among which are a few organic remains. In the rocks of this system are the first traces of fossil remains, and among them the first evidences of organic life; those found belong to the genera Cyathophyllum, Terebratula, Spirifera, Leptæna, or Producta. Some of the Cambrian and Welsh rocks have a mechanical origin: they contain marine organic remains, and have evidently been deposited by water; but it is extraordinary that they are not only stratified, but have cleavage planes inclined at a very considerable angle to the planes of the strata, and are never coincident, although in some cases they seem almost parallel with them. In Wales the cleavage planes occasionally dip towards the same point of the compass as those of stratification, but more generally in an opposite direction. The joints are undoubtedly natural fissures, which traverse these rocks in straight and well-defined lines, the whole mass being frequently split by them into regular and symmetrical shaped blocks, which affords great facility in removing them from the quarry. These natural fissures have been produced since the deposition of the strata.

Slate is an argillaceous deposit, and the clay slate resembles in a great degree decomposed felspar, which has been deprived of its potash by the action of water, and under particular circumstances powdered blue slate, acted upon by great heat and an alkali, has been transformed into white and glassy crystalline grains of felspar.

In greywacke slate the laminæ of deposition show, on all the vertical planes, being parallel, or nearly so, to the plane of stratification, which differs from the clay slate, for their lamina, as has been stated, cross the planes of stratification, so that it may be split almost indefinitely into thin plates, in a nearly vertical direction; there are instances where the laminæ of deposition remain in clay slate; across the cleavage plane are often seen stripes of colour, different from the mass, which are evidently the marks of deposition interrupted by water. The most cleavable slate rock in the quarry shows a stratified deposition, although it is perfectly crystalline in its regular structure.

Cleavage has been thought, and probably is, the result of some agency after the sediment was deposited; it is most perfect in the ancient argillaceous strata, where the rocks are of the finest grain and uniform in their character. Heat operating upon argillaceous sediment, so as to overcome the natural horizontal lamination, is supposed to have induced a new, almost crystalline fissility in vertical or highly inclined planes, having one general direction. The lower slates are universally cleavable, whilst the upper are only partially so, and the polarity of the cleavage is the result of some general agency, which no doubt directed the molecular attraction.

Gneiss System.—The materials which compose these rocks are siliceous, argillaceous, and calcareous, in a different state of aggregation to those before described. The siliceous strata is composed of the same materials as those found in the secondary sandstones, quartz, felspar, and mica, but are not so worn by attrition, and bear some resemblance to granite.

The Argillaceous Strata do not much differ from the common clays, but from their indurated character must have undergone different changes; the prevalent colours are blue, red, purple, grey, and yellow; the green varieties contain chlorite.

Primary Limestone is met with in irregular beds, alternating with all the members of the primary series; it has a highly crystalline texture, is compact, and both large and fine grained; the purest and whitest are sometimes called saccharine limestone. In the mountains at Carrara it is abundantly found, and contains no fossils; it was once supposed that this marble was formed before the existence of organic beings, but it has been proved to be a mere change of the limestone of the oolitic period. The calcareous rocks around the bay of Spezia contain abundant fossils of the oolitic system, and exhibit a difference of character in proportion as they have been acted upon more or less by the Trappean and Plutonic rocks.

Quartz Rock, being divided by natural joints, breaks into rectangular or rhomboidal forms; its structure is rarely compact and crystalline throughout; it is sometimes mixed with felspar, and sometimes with mica; it is of a white colour, but when impure it is either red or yellow.

Talcose Schist consists of talc alone, or quartz and talc; it is found in thin beds, and often passes into argillaceous schist.

Chlorite Schist is distinguishable by its green colour, and is saponaceous to the touch; its chief ingredients are chlorite and quartz, sometimes mixed with felspar and hornblende. It is most frequently found with mica schist, into which it passes.

Hornblende Schist is chiefly composed of felspar and hornblende, containing occasionally grains of quartz; it is rarely met with in large masses, but is usually associated with gneiss.

Mica Schist is a crystalline compound of quartz and mica in different proportions; its texture is foliated or laminar, and it may sometimes be split into coarse plates. When it

has a granular texture, the quartz grains are united by a crystalline cement of the same mineral.

Gneiss is composed of quartz, felspar, mica, and hornblende, the same ingredients which are found in granite, although the proportions vary. The character in which gneiss most differs is in its having the mica and hornblende arranged in planes parallel to the stratification, so that it may often be cleaved into plates. Its stratification is, however, irregular and contorted; it usually rests upon granite. The whole of the rocks of the gneiss system, after being deposited by water, have been acted upon by heat, and acquired a highly crystalline character; they are wholly devoid of organic remains, and in Britain contain no distinct fragments of other rocks, either angular or rounded.

Plutonic or Unstratified Rocks. — *Granite* is a compound crystalline rock, containing quartz, felspar, and mica; each of these bodies are composed of several elementary substances; they are intimately joined together, but without any base or cement: they vary in quantity: felspar usually predominates, and mica is less frequently present; they differ also in magnitude, alternating from large to small grains. In some varieties the concretions of felspar and quartz are several inches in size, and the mica occurs in plates upwards of a foot square, whilst in others the grain is so small that the granite appears nearly compact. The crystals of granite are seldom arranged regularly, as in gneiss, but are united in a confused crystallisation.

The Graphic Granite is a variety compounded of felspar and quartz, arranged so as to produce a laminar structure. The felspar crystals seem first to have been formed, and afterwards the darker-coloured quartz.

Aberdeen Granite sometimes has the mica replaced by hornblende, and there are varieties composed of hornblende and felspar.

Porphyritic Granite contains large crystals of felspar, held together in a granitic base in which are specks of mica of an hexagonal form. The uniform character of granite seems to indicate that, after its elements were mixed together, they were crystallised at the same time and under the same process. The minerals which constitute the granitic as well as the volcanic rocks are silica, alumina, magnesia, lime, soda, potash, and iron, and the presence of these seven elements in certain proportions is more favourable to the granitic structure: the fine grain it sometimes assumes is perhaps owing to the manner in which it has cooled.

Granite composed of quartz two parts, felspar two parts, and mica one part, is represented in the first column. Porphyritic granite in column the second, and composed of two parts quartz, three parts felspar, and one part mica. In the third column is shown a binary granite of three parts felspar and two parts quartz.

	No. 1.	No. 2.	No. 3.
Silica	74·84	73·04	75·1
Alumina	12·80	13·83	10·9
Potash	7·48	8·51	9·8
Magnesia	0·99	0·83	
Lime	0·37	0·44	0·5
Oxide of iron	1·93	1·73	0·4
Oxide of manganese	0·12	0·10	
Fluoric acid	0·21	0·18	

Granite, when reduced to very fine grains, cannot be distinguished from felspar porphyry.

Syenite is a compound of compact or crystallised felspar, united with hornblende and quartz: where the proportions are equal the first column shows the ingredients; when composed of equal proportions of quartz, felspar, and mica, they are found in the second column; and when of schorl rock and quartz in equal parts in the third column.

	No. 1.	No. 2.	No. 3.
Silica	69·91	63·96	68·01
Alumina	10·37	14·32	17·91
Potash	4·55	5·94	0·35 soda.
Lime	4·86	3·73	0·14
Magnesia	6·26	5·94	2·22
Oxide of iron	2·69	4·06	6·85
Oxide of manganese	0·07	0·21	0·81
Fluoric acid	0·50	0·65	1·79

Greenstone is composed also of compact and crystallised felspar, hornblende, or augite; its texture is sometimes earthy, but when crystalline it resembles syenite, the difference being only its green colour; its compounds are found in the first column.

Hypersthene rock is of a white or red colour, and the felspar is compact or crystallised; its compounds are in the second column.

Diallage or Serpentine may be considered as a hydrated subsilicate of magnesia; its compounds are in the third column. It should be observed that the felspar and hornblende are in equal quantities in the greenstone; the felspar and hypersthene in equal parts in column two; and in the third column the proportions are two-thirds of common felspar and one-third of diallage.

	No. 1.	No. 2.	No. 3.
Silica	54·86	59·14	58·42
Alumina	15·56	10·59	13·86
Potash	6·83	6·83	9·10
Lime	7·29	1·13	4·87
Magnesia	9·39	7·00	8·13
Oxide of iron	4·03	12·62	2·00
Oxide of manganese	0·11		
Fluoric acid	0·75		
Water		0·20	1·06

Water.—This important element occupies about three-fourths of the whole surface of the globe, and geological researches having dispelled the many fanciful theories that existed on this interesting subject, it is generally agreed that within its depths the various matters and crystallised bodies which now constitute the dry land have been precipitated, from the disintegration of other lands no longer existing. Of the period of time during which these changes were going on it would be useless to speculate; the "Medals of Creation" will enable us to class in some measure the great transitions, but they afford us no fixed dates.

At all temperatures above 32° water remains in a liquid state; when cooled below this it is congealed, and becomes solid, forming prismatic crystals, which lie across each other at angles of 60° and 120°. During the formation of ice the mass is increased in bulk a ninth part, and its expansive powers become greater, which, acting mechanically upon rocks or other earthy matter, breaks them up into smaller masses, and it thus becomes a powerful agent in the destruction of cliffs, or even mountains, though by slow degrees, and by successive operations. When the temperature of water is raised to 212°, it passes off into steam, though it is found in a state of vapour at all temperatures under pressure.

The atmosphere contains a large quantity of water, and it may be called the great receptacle of that element; all the moisture carried away by evaporation from the ocean and land enters the atmosphere as vapour, where it floats, until, being driven against higher land, it is converted into water in the form of rain or snow by condensation, and again drained off to the ocean.

Water in its ordinary state is frequently found to contain foreign matter, which renders it totally unfit for domestic uses. Rain water, if collected with care, is the most pure, but in it there are small quantities of carbonic acid and atmospheric air, as well as appreciable traces of vegetable and animal matter, which occasion it, when kept for a length of time, to become putrid.

Water is sometimes designated hard and soft, and these states may be ascertained by dropping into it a solution of soap dissolved in alcohol, which will produce at once a milky effect, if it contains any earthy or metallic salts, the presence of which constitutes its hardness, and throw them down in a flocculent precipitate.

There are five great seas or basins from whence the earth derives the supply of moisture so necessary for its fertility, and the existence of its various inhabitants.

The Pacific Ocean is of vast extent, and derives its name from the quiet of its waters, particularly between 10° and 30° of north latitude, where it is almost always calm. This sea extends 8700 leagues from east to west, and 2700 in the other direction. The coasts of America and Asia are its boundaries, and in the midst of this world of waters rise up numerous islands and coral reefs, which have their foundation at immense depths, and present a perpendicular face from the bottom to their surface.

The Atlantic Ocean, which receives the waters of some of the largest rivers of the world, is not more than half the area of the Pacific.

The Indian Ocean is in length and breadth about 1500 leagues.

The Arctic Ocean surrounds the north pole, and is a vast circular basin, which, by means of two channels, connects the Pacific and the Atlantic.

The Antarctic unites the Indian Ocean and the Pacific.

The Mediterranean is 2300 miles in length, and 650 in breadth; the Straits of Gibraltar uniting it with the Atlantic, and the Dardanelles with the Black Sea, beyond which is the Sea of Azoph: still further lies the Caspian, which has apparently no communication with the ocean.

The Baltic Sea is 1200 miles in length, and nearly 100 in breadth, and unites with the German Ocean.

The water in the northern and southern hemispheres differs considerably in quantity: in the former the proportions between land and water are as 72 to 100, and in the latter only

as 15 to 100. It is impossible with our present means to define the height at which the waters stand, or the level of the ocean, from the constant motion to which it is subjected from winds and currents. Its greatest depth has never been fathomed, and it has rarely been sounded beyond a mile; 800 or 900 fathoms were reached by the sea-clamms by Captain Parry in latitude 74° 30′ north, and 78° 1′ west longitude.

The specific gravity of sea-water is the same in nearly all latitudes when examined at a distance, from the discharge of fresh-water poured in by the rivers; its mean is about 1·02757, though, from the impurities it holds in solution, this must necessarily differ; these consist of muriate of lime, magnesia, potash, and other matters.

The colour of the sea varies, probably from the different animal and vegetable matters diffused through it in a putrescent state; it is often a blue green, and at the Tropics an azure blue, in the Mediterranean of a beautiful purple tinge.

The temperature differs according to the latitudes and depths, and seasons of the year: at the equator it is from 80° to 82°; at the temperate zones it is higher in the winter than in summer. The decrease of heat is calculated at about one degree for each degree of latitude. The cold increases with the depth in the tropical seas, whilst in higher latitudes the reverse law is observed.

The prevailing currents have two directions; those which originate in the Tropics go round the globe in a western direction, and those of the polar seas in the direction of the equator.

Between thirty degrees north and the same of south latitude, the western current moves with a velocity of about ten miles a-day; in the Atlantic it takes two directions, one of which passes to the Cape Verde Islands round the Gulf of Mexico, through the Bahama channel, and along the coasts of North America; it again alters its course at Newfoundland, and proceeds in a south-eastern direction to the Canary Islands, and then joins the stream from whence it took its departure.

The North Atlantic Ocean has a current between 11° and 43°, extending 3800 leagues, its velocity increasing as its breadth and depth becomes contracted; at the Bahama channel its breadth is 51 leagues, and its motion is as much as five miles per hour. This current returns to the Azores at the rate of seven or eight miles per day, where its breadth has been computed at 160 leagues. The space comprised between these two currents is still water, and is 140 leagues in breadth. These currents exercise a very powerful effect on the coasts, causing a continual erosion on those that are bold and rugged, whose detritus falls down into the ocean, and is carried away to be deposited in less turbulent waters, and perhaps become the foundation of some future island.

The waves of the sea depend upon the force of the wind, which, by depressing or moving a body of water, at once alters its equilibrium. When water is placed in a bent tube, and made to ascend and descend alternately, its motion agrees, with that of the pendulum, which Newton compared to the action of the waves, and found that their velocity was as the square roots of their breadths, as taken between the tops of their ridges; and he also found that waves moved through a space equal to their breadth in the same time in which a pendulum oscillated, whose length was equal to its breadth. Waves, whose breadth are 39⅛ inches, will move over that distance in a second of time, and their motion is progressive; but an object floating on their surface seems to make little way, and their motion does not appear to be so considerable.

The tidal currents, which alternately move in opposite directions, exercise a considerable destroying action on the land, as well as on the formations in progress at the bottom of the ocean. The motion of the tides and currents is produced by different means; the first is from the influence of the sun and moon, and their height and velocity depend upon the coasts within which they are enclosed. In narrow seas they rise higher, but when the waters meet with no obstruction and can freely expand, they do not exhibit so much elevation. In the Bristol Channel, where the passage is narrow, the tide runs at the rate of 14 miles an hour. In the ocean are permanent currents from 50 to 250 miles in breadth, which constantly flow in the same direction, in consequence of the influence of particular winds, or from the expansion and contraction that the waters of the sea are subjected to when acted upon by heat or cold, which change the condition of their temperature.

The currents towards the Tropics from the poles are produced by the increase of specific gravity of the water as it becomes colder, which occasions it to sink, and thus allows that which is warmer, and consequently lighter, to float at the surface. Thus rising and descending currents are produced, the lower parts of the ocean in high latitudes become of higher specific gravity than those at the same depth between the Tropics; the cold water rushing to occupy the lower place of that more highly rarified, which, in its turn, moves forward in the opposite direction.

The tides are not affected entirely by the moon's influence; the sun has considerable power, which has been estimated at about one-fourth of the whole. When the sun and moon are in conjunction or opposition, and exert their combined influence in elevating the waters of the ocean in the same direction, they rise to the height called a *spring-tide*; this

effect is shown in the diagram, where the sun, S, and the moon, M, are supposed to be drawing the waters of the earth, A B C D. The moon's action alone is shown by the spheroid *c h g f*, and the combined effect of both sun and moon by the spheroid E F G H. When the moon is in quadrature with the sun, the action of the one diminishes the effect of the

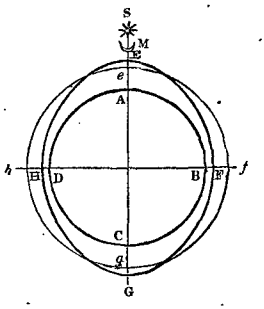


Fig. 581.

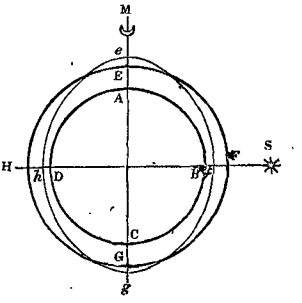


Fig. 582.

other, as shown in the figure *e f g h*; the moon would have produced the effect, but as the sun's attraction depresses the water at *e* and *g*, and raises it at *f* and *h*, the combined effect of the two luminaries will be that shown at E F G H, and such an effect is called a *neap-tide*.

The highest spring-tide does not occur immediately after the new or full moon, but about the third or fourth tide afterwards, and the lowest neap about the same time after the quarters.

The magnitude of a tide is the difference between the highest flood and the lowest ebb during the same day.

The high and low state of the tide occur twice during a lunar day, or at the rate of 12 hours 25 minutes and 14 seconds. The tide is, however, 9 or 10 minutes longer ebbing than flowing, and the higher it is at the ebb, the lower it generally sinks on the same day.

The atmosphere is subject to elevations and depressions like those of the sea, and cause variations that affect the winds and weather; but their influence cannot be very great, for the addition of a few feet to the height of the atmosphere would be productive of little change. The height of an aerial tide must correspond with the height of the observable tides of the ocean, and the alteration of atmospheric pressure may be measured by the difference between the actual form and the spheroid of equilibrium. Near the equator there is a periodical variation in the state of the atmosphere far greater than in our climate, but which is not caused by the action of the moon, as it happens regularly at the same hour of both day and night. The atmosphere is affected by a current from east to west, like that of the sea, which is attributed to the attraction of both sun and moon. Since Newton explained his theory of the tides, and the effects of the laws of gravitation, the theory has been much improved by the labours of later mathematicians: but no problems are more difficult to solve than those which belongs to such investigations; and the causes and circumstances upon which they are dependent are so remote, that it is more than probable they will remain for a length of time unknown to us; and it is absolutely necessary, before we can arrive at a conclusion, that we should have ascertained the depth of the sea throughout the globe.

The great wave which follows the moon, *or the tide*, is an undulation in which there is not much progressive motion, except where it approaches the shore; and the usual time of high water is about two or three hours after the moon is on the meridian.

Where the passage of this wave is confined, the tides are not the result immediately of the sun and moon; the narrowing the mass of water elevates their level considerably; this is very evident where the waters of the Atlantic are opposed by the coast of Ireland, and divided into three different branches, one passing up the British Channel, another west of Ireland and Scotland, and the third into the Irish Channel. The first of these moves at a rate of 50 miles an hour, and passes through the Dover Straits, so as to reach the Nore at midnight during spring tides.

The second branch is more rapid, reaching the north of Ireland six hours before; three hours afterwards it has arrived at the Orkney Islands, and three hours more, or at twelve o'clock, we find the same wave, extending eastward to the Naze of Norway; twelve hours afterwards, it has progressed through the German Ocean, and arrived at the Nore, meeting the morning tide, that left the mouth of the channel only eight hours previously, so that

these two tides make the circuit of Britain in twenty-eight hours, during which period the primitive tide has made the circuit of the globe, and nearly 45° in addition.

High water on the Thames at London bridge takes place at the moment when it is low water at the mouth of the river, the surface of the water at London being 40 feet above its level at the German Ocean at the same time.

Large rivers in which the tides occur do not have a regular descent of surface towards the sea, but a varied outline produced by continual motion.

The Bore, which is an accumulation of water in large rivers at the time of flood, arises from the narrowness of the outlet preventing the entire discharge of the water before the return of the next tide, which it meets as it flows in an opposite direction, and consequently causes an elevation of water above its natural level, and which is often extremely dangerous to small craft and to navigation. The wave so formed rolls with great violence up the river, pressed forwards by the accumulating force of the tide, until it is lost or dies away. In the river Severn the bore often rises 10 feet, and in the Amazon it is said to mount upwards of 100.

A variety of instruments are made use of in our harbours to measure the tides; that which is found to answer the best is formed of a pole, 24 feet in length, and 6 inches in diameter, supported upon legs firmly lashed together with ropes, ballasted with pig-iron laid over the bottom. On the pole is placed a perpendicular graduated scale, made of deal or other wood, and the whole is kept steady by several guy ropes attached to the top.

Measuring rods, made of $\frac{3}{4}$ inch deal, with a cork float at the bottom, in the form of a cube of 3 inches, work in boxes attached to the pole: these rods, graduated in feet and inches, pass through staples which steady them; and as the water is admitted into the boxes through a hole in the bottom, the rods rise with it, indicating to what height in a given time the tide rises or falls.

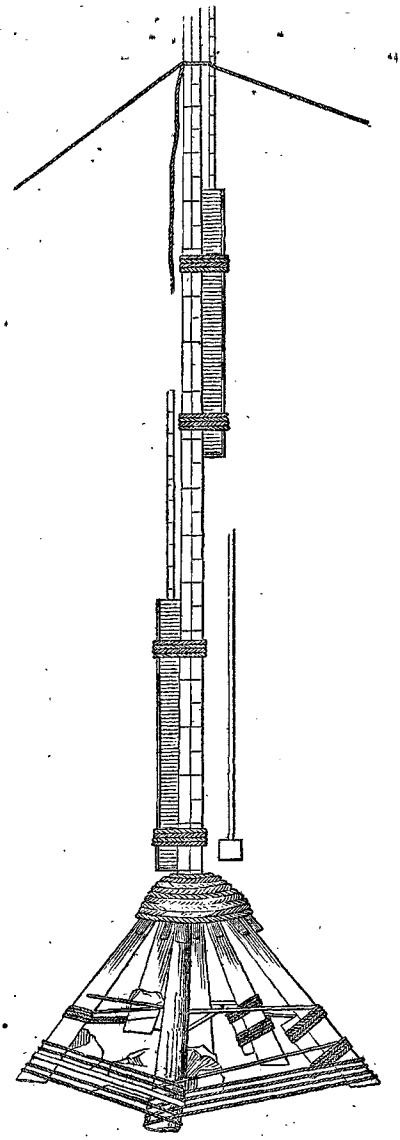


Fig. 583. TIDE GAUGE.

Origin of Rivers.—The condensation of vapour on the tops of the highest mountains is the origin of some of the largest rivers, and the source of all is dependent upon meteorological causes. That water which falls from the clouds and enters some depth into the earth again issues forth as a spring, and, gaining strength in its course by the addition of other streamlets, continues to flow on till it reaches the ocean, after being sometimes diverted in its course by the various obstacles that are opposed to it. On tracing the descent of a river, we perceive that the gradation from masses of rock to grains of fine sand is almost imperceptible. At its commencement the water trickles drop by drop from the ledges of the rock, whose cold and rugged sides have condensed the vapour brought from the ocean; these drops unite, and run down the acclivities in small veins, which in their course receive others, until by accumulation they attain the character of a river. The quantity of rain that falls must affect the state of a river. This varies in different districts; in the neighbourhood of Paris it annually amounts to 18 or 20 inches; at Milan, in the north of Italy, to 40, and in many mountainous districts to 90 or 100 inches; the summits of the Alps

and Apennines, and all mountainous regions, are usually covered with snow, so that there is a perpetual humidity in the loftier regions of the earth, until we arrive at that station where, for the greatest part of the year, the whole is congealed by extreme cold.

The Seine has in the summer not more than 3 feet depth of water, though in time of high floods it has been known to rise nearly 23 feet. The Po, in Italy, during floods does not increase in breadth, but quadruples its height, so that the quantity of water poured down in one day is equal to eight times that which flows on ordinary occasions. The river Thames drains an area of a little more than 5000 square miles, and taking the average depth of rain that falls in a year at 24 inches, it has been computed that 239,765,120,000 cubic feet of water annually pass down this great natural drainage into the ocean, to be again returned by evaporation.

Were it not for floods, the beds of rivers and their banks would undergo little alteration: when, however, they occur, as they do in many districts periodically, the large stones are moved forward, and rounded by attrition, whilst their debris, and the fine gravels and sands whose specific gravity varies little from that of the water, are carried along by the force of the current, and are not deposited till they meet with still water, or are taken out to sea, where the motion of the fresh water is opposed or staid altogether.

Beds of rivers are constantly raised by the stones, gravel and sand brought down at the time of flood: this is evident, when we take into consideration the enormous quantities of ballast dredged from our rivers, in order to keep their channels open for the purposes of navigation. It thus becomes necessary to elevate the banks, which is often continued beyond the limits that are beneficial to the drainage of the neighbouring land. When a bar or shoal is thrown up, if not cleared away, it acts like a dam or artificial wall, preventing first the free passage of the heavy stones, which are consequently deposited until the bed is raised to the level of the impediment. In many instances where the foundations of buildings have been laid considerably above the level of the water, we find them now sunk one or more stories below it, and the whole drainage of a city destroyed by either natural impediments in the slope of rivers, or some artificial contrivance to benefit machinery constructed on its banks. Throughout England the proprietors of mills have been suffered to increase their fall, not by dredging the bed of the tail-water, but by raising the banks through which the water was conducted to the sill; thus destroying the use of a river as the natural drain of a country, by elevating its bed above the ordinary level of that part of the valley where the mill is situated. Wherever a head of water is created in a valley, it does an infinite mischief in penning back, by its weight, the springs which endeavour to find a vent at the foot of the hills, and which the river, when left to itself, would carry off.

Mill-dams, when thrown across a stream, occasion a deposition of all that is brought down, and thus elevate the upper parts of the beds, as well as affect all the tributary streams that are within its influence. When a succession of drains occur, they materially change the natural slope of the bed; for whatever the water tumbles over occasions it to acquire an increased velocity, and deepens the channel for some distance, pushing as it were the bed forwards, so that if the section of such a stream were taken, we should find ascending concavities rising to the level of each successive dam instead of a regular slope. When the velocity of a stream depends upon its fall, it is materially altered by the introduction of a dam; and when the velocity is diminished the natural slopes in the bed are all changed, and new depositions are the consequence. In muddy streams, where no impediment occurs in the way, or any dam offers itself to oppose the force of the floods, the whole trunk becomes scoured out, and the natural slope is maintained. Where the slope of the bed of a river varies, there we always have a difference in the velocity of the running waters. By augmenting the force of a stream, any deposits may be pushed onwards; and this may be done by uniting several others with it, thus increasing its height, or by making the course shorter through which it flows, which has the effect of distributing its fall over a less distance. Gravels will not always move forwards with the ordinary power that is exerted upon them; they will generally accumulate to such a degree as to drive the river from its channel, and find some new course. This is not the case with rivers flowing over a bed of sand, where the current is seldom changed from its original direction. When a river through a gravel is shortened, by making it flow in a straighter direction, the bed in the upper part is lowered, and the portions pushed forward elevate the bed below the point where the cut terminated, which will be the case with every successive portion, until in the course of time it ceases to admit the vessels or boats, which formerly navigated it, to the serious injury of the surrounding neighbourhood; such are the too frequent results, when improvements, so called, are suggested or undertaken by persons ignorant of the elements which they have to manage.

In straight rivers we find the gravel more easily pushed forward than in those which have a meandering course, and it is first deposited at the bottom, at the greatest distance, where it gradually raises the lower parts, and then those higher up the stream: this in time requires the embankments to be elevated, to prevent an overflow when floods occur.

Rivers that carry gravels should never have their course shortened without well considering all the consequences likely to ensue. When it is required to alter the course of a river, to shorten it, or to unite other streams with it, the new bed should always be made to pass below the utmost limits of the gravel. In all cases let nature be the guide; she often brings together, amidst rocks and mountain precipices, various streams, but seldom or never whilst they bear down gravel does she unite them in the plains with those which carry mud or sand. Wherever any cut has been made to shorten a river flowing over gravel, its success has been uncertain; and when it is attempted, care should always be taken that the fall of the new channel is not less than that of the old one. Streams may be united without much danger if they all carry the same substances, and there is sufficient fall and velocity to bear them to their utmost limits; the success of the undertaking may then be relied upon.

The velocity with which water moves arises from the pressure of the upper parts, and is in proportion to the number of pressing particles, or as the height. These velocities are computed to be as the square roots of their heights, but it is not possible, for any practical purposes, to make use of the solutions of such hydraulic problems; the difficulties seem to increase with the several conditions of the examples, and the better way for the engineer is to resort to direct experiment. The velocity of water has but one law, and is always proportional to the square root of the height; this law is the same which belongs to all falling bodies, passing in a second of time through a given space. If a parabola be formed with its abscissa made to represent the space the falling body passes in a second of time, and the corresponding semi-ordinate to represent double that space, or what it would fall in two seconds; then all the other semi-ordinates will express velocities corresponding with the height of their respective abscissas; and by dividing the square of the semi-ordinate by its abscissa, the parameter of the parabola will be obtained.

To ascertain the velocity at the surface of a river, it is only necessary to measure the space through which a floating body moves in any given time, or to notice the float-boards of a wheel, and count the number of times they strike the surface of the stream, and then count its revolutions in a given time, or to measure with a quadrant how far a weight suspended from its centre is diverted from the perpendicular by the force of the stream; it being ascertained that the tangents of the elevations of pendulums ought to be proportional to the stroke and force of the stream, viz. to the velocity and the number of particles which strike it in a given time, or, in other words, to the square of the velocity. After this has been done, ascertain what height will correspond with this velocity, or from what height a body must fall to acquire a velocity equal to that with which the surface of the river is moving, and then add this height to the whole height of the section, to obtain the effective height, with which the actual velocity agrees.

The space run through in a second by a floating body at the surface, divided by the same parameter, will give the height due to the velocity of the surface, which, added to the actual height of the river, will give the whole effective or equivalent height.

The square-root of the product of the equivalent height by the parameter will give the velocity at the bottom of the section.

Two-thirds of the product of the velocity at the bottom, by the whole equivalent height, minus two-thirds of the product of the velocity at the surface, by the height added to the actual height, will give the mean velocity.

Finally the product of the mean velocity by the actual breadth and the actual height will give the quantity of water that passes in one second through the rectangular section.

Where the section is a trapezium it is necessary to calculate the quantity of water which passes through all the perpendiculars of the triangle formed about the greatest inscribed rectangle, but the method of calculation is the same.

When the height of the water is stated, as well as the figure or form of the opening described through which it flows, it will be easy to ascertain the quantity given out in any certain time.

Supposing the aperture to be *square*, one side of which touches the surface of the water at rest in a cistern or reservoir, or a *circle* inscribed in the square, or a triangle with the vertex upwards, or *downwards*, or with one having the same height and vertex, but with only half its base; then the quantity of water flowing through these apertures in equal times will be as 5, 4, 3, 2, and 1, and it has been found that through a circular hole 1 inch in diameter, immersed $\frac{1}{12}$ below the surface of the water, there will flow out $13\frac{1}{2}$ pints in 1 minute of time.

The velocity of a river depends on its fall, or on the pressure of its upper parts: all the particles of which it is composed in descending are moved forwards by the ordinary laws. The acceleration from pressure puts them in motion, and the slope of the bed contributes chiefly to their progressive advancement, by the pressure of the higher parts of the stream and its current in the plains, where the slope of its bed is trifling, and the body of water is materially increased.

Rivers near their discharge often obtain a much greater velocity than they had at their commencement, from the increase of their body of water.

The slopes or beds of rivers differ materially in their inclination, and we often find them cutting deep chasms through lofty mountains, or taking their course through ravines or fissures caused by some convulsive movement of the earth itself. Where the river passes over or through a district of alkaline or calcareous rocks, which are soluble in water, the carbonic acid of the water dissolves them, and wears away by degrees these apparently hard and indestructible substances, often acting at the base of a hill or mountain, undermining them, and masses fall into the torrent, to be carried lower down the next flood.

When two rivers fall into one channel, the height of the water does not increase in proportion to the body by which it is augmented; so that when a considerable quantity of water is added to a stream, there is only an increase of velocity. If the height of the sections of twenty or more tributary streams were added to that of the trunk they fall into, this fact would be made evident. When the Mayne, which is more than half the size of the Rhine, unites with that stream, there is no apparent increase, and where divided into two or more channels, its height is not lowered. The Inn falls into the Danube, and both rivers, nearly equal in size, then pursue one course, without becoming either broader or deeper.

The Po has no apparent increase after it has received the Secchio and Panaro; and the Tiber receiving the Teverone is neither deepened nor widened, and so it is with other rivers. Pliny, in one of his letters to the emperor Trajan, observes that the canal cut by Nerva to draw off the superfluous waters of the Tiber, did not in any degree prevent the inundations of which it was the cause. The two sections above and below this canal, called the Fiumicino, are nearly of the same breadth; the depth in the upper is 7 feet 4 inches, and the whole section is a rectangle; the depth of the lower is 6 feet 8 inches on one side, and 13 on the other; but when the areas of the two sections are accurately computed, they are found to be similar.

Rivers which carry sands in the lower parts of their beds have less slope than at the upper; their declivity diminishes in proportion to the distance they have run from their sources; this is caused by the diminution of the size of the particles as they progress, which consequently require less force to push them forward, and are borne to the very extremity before they are deposited; where these light substances are floated, less declivity is needed to keep the bed of the stream clear of obstruction. The body of water being the same, the slope of the bottom may be said to diminish in proportion as the matter brought down becomes smaller, and is more easily moved onwards on this account.

Rivers which are increased by their union with others that are less require less fall than before; for if the slopes of all the small streams which unite to form one be measured, it will be found that their declivity is much greater before than after their junction, so that the greater the ordinary body of water in a river, the less will be the slope of its bed.

Whenever the freshes of a tributary stream fall into another, the recipient flows back, depositing its sediment above the mouth, as well as below it, if the assistance which the former receives from the low waters is insufficient to compensate for the difference of fall which the tributary encounters in passing from its own into the common bed.

It appears to be a common law that the greater the quantity of water a river carries, the less will be its fall, and the greater the force of the stream, the less will be the slope of its bed, and the slope of the bottom of rivers diminishes in proportion, as the body of water is increased.

Tacitus relates in his Annals, that when a proposition was made to the Roman senate to divert into other channels all the rivers which flowed into the Tiber, the opinion of Piso was followed; he advised that no alteration should be made, since every one might see that nature knew how to provide for her wants much better than could be done by art; she assigned to rivers their sources, boundaries, and limits the most suitable. Nature, however, exhibits at times singular phenomena, where rivers discharge themselves into the sea, by spreading their waters over its surface. At a considerable distance from the land, they often run over a bottom having a very small declivity, but which at the mouth of the river is bent downwards, forming a deep concavity; this is the case with some of the largest rivers, where the tides are apparent at a considerable distance up them.

The sea-water during the time of flood-tide, entering the river, and at ebb returning, helps to produce this effect, and to render the section of the bed a concave line, by sweeping away all the deposits lodged where this action takes place; so that shoals are not formed so long as a river can keep its mouth open on a flat shore, the particles brought down being deposited either above or below the spot where they discharge themselves.

Deltas at the mouth of rivers arise from the deposit of the detritus they carry in their course; this in time rises to the surface, forms a bar, turning the river into another channel. On a flat coast there is usually the most deposit, and sometimes what is brought down is carried into a current in the ocean, and afterwards deposited on some other coast,

or formed into islands elsewhere; the quantity of earthy matter depends upon the nature of the river that discharges itself.

The Rhone, which passes through the Lake of Geneva, there deposits much of the matter it brings down from the glaciers of Mont-Blanc, but it acquires in its after-course a considerable accession from the tributary streams of the Alps of Dauphiny. This river pours itself into the Mediterranean, which it discolours for a distance of 7 miles from its mouth, depositing a fine sediment in horizontal strata along the whole shore over which its water spreads: since the time this coast was under the dominion of the Romans its harbours have been silted up, and are now a league from the shore.

The Po has poured out so much sediment, received from the Alps and Pyrenees, that where it is discharged in the sea not under the influence of a tide, it has added to the coast, for a length of 100 miles, a breadth of land in some places as much as 20 miles. Adria, a town of importance, and which gave the name to the sea that washed its walls, is now 20 miles within land; this increase of land has been more rapid as the embankments of the various rivers have been elevated.

The Nile, which discharges 250 times as much water as the Thames, deposits its detritus in its course over the fertile lands of Egypt, which it irrigates; therefore its delta is small in comparison with that formed by other large rivers. The land of Egypt is calculated to have been raised above 6 feet in height since the commencement of the Christian æra; and the earth deposited is about half argillaceous, a fourth carbonate of lime, and the remainder carbonate of magnesia and oxide of iron. The delta of the Nile at its termination has a depth of sea of 2000 feet or more. The seven mouths of this noble river are no longer open; five of them are silted up, as is the Lake Maræotis.

The Mississippi empties itself into the Gulf of Mexico after a course of 3000 miles, and often brings down with it whole forests, and large quantities of alluvial matter.

The Ganges and Brahmapoutra, which bring the water from the Himalaya mountains, are discharged into the Bay of Bengal; the delta at the mouth reaches 200 miles along the coast, and commences 220 miles from the sea. The tide extends its influence to the head of this delta when the river is low, and the sea for a distance of 60 miles in times of floods is discoloured by the alluvial matter, which chiefly consists of sand and silt borne by the tidal current to a distance of 400 miles. In one direction a tract of land 40 miles square and 114 miles in depth has been washed away in the course of a few years; and it has been stated, on the authority of Major Rennel, that the deposits forming the Sunderbunds equal in extent the area of the whole of Wales.

The Delta of the Niger stretches 300 miles along the coast, and extends 170 miles into the interior.

Quantity of Water discharged by Rivers.—This is found to be the annual produce of the rain that falls over the several districts, in which they act as a natural drain, after deducting about $\frac{1}{4}$ for filtration and evaporation, and the total expenditure of a river may be deduced by the products of its mean section and mean velocity. Buffon estimated the area of all the land to be equal to 63,728,938 square miles, and the mean quantity of rain to be equal to 36 inches; if then we calculate the quantity carried down by such a river as the Po, we shall find that it would be necessary to have 1400 such rivers; the Po having a mean breadth of 1000 feet, and its waters moving with a velocity of 4 miles an hour.

The annual discharge of the Rhine at Bayle is estimated at 1,046,763,676,000 cubic feet. The Tay at Perth, in Scotland, 100,000,000,000 cubic feet. The Thames, which drains upwards of 5000 square miles, according to Dr. Halley's observation made at Kingston Bridge, 239,765,120,000 cubic feet per annum; but it is doubted whether any of these calculations are to be depended upon.

Sand Banks.—The Dogger Bank is 350 miles in length, and that in the Firth of Forth 110 miles, and their average height is about 80 feet. The area of these two banks is about $\frac{1}{3}$ of the German Ocean, and almost equal in extent to $\frac{1}{3}$ of England and Scotland; they are formed of sand mixed with broken shells and corals, and have been thrown up by the tidal current.

Downs or Dunes are formed on a low coast, where the bottom is composed of sand: this being driven by the waves towards the shore is left dry on every reflux of the tide; the winds which blow from the sea then carry them inland, and form sandy flats and hills. These sometimes occur at the mouths of rivers, and such a sand flood, as it is termed, effectually stops the passage of the water, driving it into some new channel.

The Beach may be divided into three portions: viz. that comprised between high water of spring and neap tides; that between high water at neaps and the extreme low water of spring tides; and the expanse of sand and gravel, of greater or less extent in proportion to the flatness or steepness of the shore, never laid dry, but covered at the lowest ebb by shallow water. These are termed high water, low water, and littoral sea beaches. The first is usually composed of shingle or round pebbles, thrown up more or less steep. The second or low water beach usually presents a gently sloping surface, strewed with pebbles or patches of sand.

CHAP. II.

OF THE COMPOSITION AND USE OF MINERALS.

THE constituents of minerals are resolved into fifty-four elementary bodies; and these are either gaseous, fluid, or in a solid state.

In the gaseous bodies the particles that compose them have no cohesion; they yield readily to pressure, and when that is removed, they expand again into their original volume.

The fluids are not elastic, and do not yield to ordinary pressure.

The solids may be changed into fluids, and fluids into gaseous bodies by the agency of heat.

Gazzolytes.
- Oxygen.
- Hydrogen.
- Nitrogen.

Halogens.
- Chlorine.
- Iodine.
- Bromine.
- Fluorine.

Metalloids.
- Sulphur.
- Selenium.
- Phosphorus.
- Carbon.
- Boron.

Metallic Bases of the Alkalies.
- Potassium.
- Sodium.
- Lithium.

Metallic Bases of the Alkaline Earths.
- Barium.
- Strontium.
- Calcium.
- Magnesium.

Metallic Bases of the Earths.
- Aluminum.
- Silicum.
- Yttrium.
- Glucinum.
- Zirconium.
- Thorium.

Common Metals whose Oxides cannot be reduced by heat alone.
- Iron.
- Lead.
- Copper.
- Zinc.
- Antimony.
- Tin.
- Bismuth.
- Manganese.
- Chromium.
- Cobalt.
- Arsenic.
- Nickel.

Common Metals whose Oxides are reduced by heat alone.
- Mercury.
- Silver.
- Gold.
- Platinum.
- Palladium.

These bodies all combine with each other with reference to their weights, and the absolute quantity of matter they contain; this constitutes the basis of the Atomic theory, proposed by the late Dr. Dalton, who established that great and important principle, which teaches that all bodies combine in definite proportions by weight, and never otherwise. Water, for instance, is composed of one volume of oxygen united with two volumes of hydrogen, the relative weights of which are as 1 to 8; the two volumes of hydrogen being considered as one atom or unity. All bodies which assume the gaseous form may have their atomic weight easily determined; carbon, for instance, which is incapable of assuming the gaseous form, will combine with oxygen and form carbonic acid gas, one volume of which weighs twenty-two times as much as the two volumes of hydrogen which we take as a standard. Twenty-two parts of carbonic acid contain sixteen of oxygen, therefore the other six must be carbon, which is the number or proportion in which this body combines with others. Carbonate of lime contains twenty-two parts of carbonic acid, and twenty-eight parts of lime, therefore the latter number is its atomic weight.

Atomic weights for almost all the bodies are now established, as is the relation in which they combine with each other; one of hydrogen combines with six of carbon, and with eight of oxygen, or, as has been stated, six of carbon combine with eight of oxygen. The equivalent or number for water, for instance, is usually stated thus, 9 = oxygen 8 + hydrogen 1. Sliding scales are made use of by chemists for aiding the calculations with respect to different combinations, and it must always be borne in mind, that these

are either exactly double, triple, or some multiple by a whole number of the smallest proportion in which the body enters into combination with the other substance. Fourteen of nitrogen can only combine with 8, 16, 24, 32, or 40 of oxygen, but with no intermediate proportion.

Oxygen is an invisible and permanently elastic gas, without taste, colour, or smell; its specific gravity, as compared with air, is 1·111 to 1·000; compared with hydrogen as 16 to 1, hydrogen being unity. At mean temperature and pressure 100 cubic inches of oxygen weigh 34·60 grains. When water is freed from air 100 cubic inches will absorb 3·5 cubic inches of oxygen; it forms $\frac{1}{3}$ of the weight of the atmosphere, $\frac{8}{9}$ of the weight of water, and is so abundant a principle in the mineral kingdom, that in silex it forms 50 per cent., in alumina 47, in lime 28, in magnesia 40, in potash 17, and in soda 25 per cent.; in the sulphate and carbonates of lime, the two most abundant acids, it is the essential ingredient. Oxygen does not occur in nature except in combination with other bodies, and it is then said that the body so containing it is oxidised, or is in a state of oxidation; its combining number is 8.

Hydrogen is the lightest form of matter known, its specific gravity, as compared with oxygen, being as 1 to 16; 100 cubic inches of pure hydrogen gas at a mean temperature and pressure weigh 2·1318 grains, and as compared with atmospheric air its specific gravity is as ·0694 to 1. It does not form a very important element in the composition of rocks, though it occurs in the animal and vegetable kingdoms in abundance. It is one of the elements of water, constituting about 11 per cent. of that compound, or $\frac{1}{9}$ of the water of the globe. Pure water, when exposed to the action of voltaic electricity, is resolved into two volumes of hydrogen, disengaged at the negative pole, and one volume of oxygen at the positive. Water therefore, consisting of one volume of hydrogen, and half a volume of oxygen, their relative weights are as 1 to 8.

	Equivalent.		Volumes.
Hydrogen	1	11·1	1·0
Oxygen	1	88·9	0·5
	1	100·0	

Pure water, at the temperature of 62°, has its specific gravity equal to 1·000; a cubic inch weighs 252·5 grains, and a cubic foot 998·217 ounces avoirdupois, so that the specific gravity of any substance in reference to water is nearly the absolute weight of 1 cubic foot of such substance in ounces avoirdupois.

Water is about 815 times the weight of atmospheric air, and at 32° it freezes, ice being of the specific gravity of 0·94. It boils at 212°, when the barometer is at 30°: 100 cubic inches of steam weigh 19,062 grains, the specific gravity of steam being ·6249. At a mean pressure, and at a temperature of 212°, the bulk of steam is 1700 times greater than that of water.

Pure hydrogen condenses half its bulk of oxygen when detonated by the electric spark, and is much employed by the chemist as a deoxidating agent; it refracts light powerfully, and is an imperfect conductor of electricity.

Water has the power of absorbing many of the gases, 500 cubic inches absorbing of

	Volumes.
Sulphuretted hydrogen	233
Carbonic oxide	100
Nitrous do.	76
Olefiant gas	12·5
Oxygen	3·7
Hydrogen	1·56
Nitrogen	1·56

Water absorbs oxygen and nitrogen from the air, condensing more of the former than the latter, and air at the surface of the earth is always found to contain water, but is scarcely ever in a pure state.

Peroxide of Hydrogen, or oxygenated water, is liquid, transparent, and inodorous; its specific gravity is 1·45, and it is decomposed by all metals except iron, tin, antimony, and tellurium. Silver and oxide of silver decompose it as well as platinum and gold. Lead and mercury more slowly disengage the oxygen.

	Equivalent.		Volume.
Hydrogen	1	5·9	1
Oxygen	2	94·1	1
	1	100·0	

Nitrogen or *Azote* is a colourless gas, without either taste or smell, incapable of supporting combustion or respiration. It has no action upon vegetable colours, or upon

lime water, nor does water absorb it, except after it has been boiled for a considerable time. Nitrogen forms four-fifths, by bulk, of atmospheric air, and is found in coal, in the nitrates, and abounds in the materials of the animal kingdom. Its specific gravity, as compared with air, is 0·976. At a mean temperature and pressure, 100 cubic inches weigh 30·16 grains. Its specific gravity, in reference to hydrogen, is 14 to 1.

Nitrous Oxide or Protoxide of Nitrogen, gaseous, colourless, with a sweet taste and slight odour, supports combustion brilliantly, and acts powerfully on the animal economy when inhaled. When agitated with water it is absorbed, taking up an equal bulk, and when heated it is evolved unchanged.

At a pressure of fifty atmospheres, this gas has been obtained in a liquid form.

Nitrogen	-	1	-	14	-	63·3	-	1·0	- 30·16
Oxygen	-	1	-	8	-	36·7	-	0·5	- 17·05
		1		22		100·0		1·0	47·21

By passing it through a bright red heat in a porcelain tube, it is resolved into oxygen, nitrogen, and nitrous acid.

Nitric Oxide or Deutoxide of Nitrogen is a colourless, uncondensible gas, and cannot be respired. When mixed with air, it combines with the oxygen, producing red fumes of nitrous acid. Its specific gravity, compared with hydrogen, is 15 to 1. 100 cubic inches weigh 32·137 grains, and compared with air, its specific gravity is as 1·038 to 1000. It is permanent over water. It is fatal to animals when breathed.

Nitrogen	-	1	-	14	-	46·67	- 1
Oxygen	-	2	-	16	-	53·33	- 1
		1		30		100·00	2

Hyponitrous Acid forms distinct salts by combining with the salifiable bases. It is liquid, green and very volatile.

Nitrogen	-	1	-	14	-	36·8	- 1·0
Oxygen	-	3	-	24	-	63·2	- 1·5
		4		38		100·0	

Nitrous Acid is used as an oxidating agent, particularly when mixed with nitric acid. Its specific gravity, as compared with hydrogen, is as 46 to 1 ; to air 3·19 to 1, and 100 cubic inches weigh 98·8 grains. When liquid it is of an orange colour, specific gravity 1·452, and boils at 82°, and a red heat decomposes it.

When nitrous acid is poured into water, it is quickly decomposed, nitric oxide is disengaged, and the fluid assumes a greenish colour.

Nitrogen	-	1	-	14	-	30·4	- 1
Oxygen	-	4	-	32	-	69·6	- 2
		1		46		100·0	1

Nitrous acid does not unite with bases, but forms with them hyponitrites and nitrates.

Nitric Acid is transparent and colourless when pure, and is decomposed when passed in vapour through a red-hot tube. Its specific gravity varies between 1·4 and 1·5, and it always contains water.

Nitrogen	-	1	-	14	-	25·9
Oxygen	-	5	-	40	-	74·1
		1		54		100·0

The salts called *Nitrates* are compounds of the anhydrous acid and a salifiable base; they are soluble in water, and crystallisable. The liquid nitric acid in its utmost state of concentration consists of

Anhydrous nitric acid		1	-	54	-	75
Water	-	2	-	18	-	25
		1		72		100

Nitric Acid is used to oxydise and dissolve the metals, and to separate them from those which are not acted upon by it, as gold and platinum.

Aqua regia is a mixture of nitric and muriatic acids, which has the power of dissolving gold and platinum. Nitrogen and hydrogen combine (N + 3 H) to form ammonia; and this gaseous compound is obtained from a mixture of quicklime and muriate of ammonia: the specific gravity of ammonia, as compared with hydrogen, is as 8·5 to 1; with air as ·590 to 1, and 100 cubical inches weigh about 18 grains: water at a temperature of 50° will take up 670 times its volume of ammonia.

Ammonia and muriatic acid constitute the sal ammonia of commerce, or the muriate of ammonia. It is constituted of

Ammonia	1	17	31·5
Muriatic acid	1	37	68·5
	1	54	100·0

Muriate of ammonia has been found serviceable in removing the incrustations formed at the bottom of boilers, which chiefly consist of carbonate of lime. A small quantity of sal ammoniac added to water in a boiler dissolves the carbonate formed, and converts it into a soluble muriate, without affecting the boiler.

Sal ammoniac is made use of in tinning, to prevent the oxidation of the surface of the copper or other metal on which it is laid.

Atmospheric air, or the atmosphere, comprising all those gaseous matters which surround the earth, is essentially composed of oxygen and azote, in the proportions of nearly one of the former to four of the latter; to which is added carbonic acid gas, and water in the state of vapour; or the quantity of each may, under ordinary circumstances, be stated thus,

Oxygen	210
Nitrogen or Azote	775
Aqueous vapour	14·2
Carbonic acid	·8
	1000·0

The pressure or weight of the atmosphere upon all parts of the surface of the earth is estimated at 15 pounds upon a square inch, which is equal to a column of mercury of the same area, 30 inches high; this pressure decreases as we ascend above the earth in regular geometrical progression; for at three miles the density is only equal to a column of mercury, 15 inches high, and at 6 only 7½ inches; at 9 miles of elevation 3¾, and at 15 miles only 1 inch. It has been consequently assumed that the atmosphere does not extend to a height of more than 45 miles, and that the greatest portion of it is comprised within 15 miles.

Chlorine, at common temperatures and pressures, is a gaseous fluid, but may be condensed into a liquid form at a temperature of 60°, and a pressure of four atmospheres. Chlorine gas is of a greenish yellow colour; its specific gravity, as compared with air, is 2·47, and 100 cubic inches at mean temperature weigh 76·59 grains. At a temperature of 60°, water dissolves two volumes of chlorine, and the solution has a specific gravity of 1·008. Chlorine has never been found pure, but in common and rock salt, it is combined with sodium in the proportion of 60 per cent.; it has a violent action on some of the metals, which, when thrown into it in a state of powder, are burnt, and enter into combination with it.

Chlorine destroys most animal and vegetable colouring matters, as well as odorous effluvia, by decomposing them, removing the hydrogen present, or by combining with the oxygen. Water absorbs about 1½ times its volume of chlorine.

Protoxide of Chlorine (*hypochlorous acid*) is pernicious to respiration; water dissolves ten volumes of this gas, which is of deep yellow colour; it destroys most vegetable colours, previously reddening the blues. The aqueous solution is rapidly decomposed by iron filings, but the other metals have little or no action upon it. Silver, however, combines with the chlorine, evolving at the same time a portion of its oxygen. Bromine, iodine, sulphur, phosphorus, selenium, and arsenic, are converted by it into their respective acids, chlorine being evolved.

Chlorine	1	36	81·75
Oxygen	1	8	18·25
	1	44	100·00

Peroxide of Chlorine is gaseous, transparent, and of a very deep greenish yellow colour. Its specific gravity, as compared with air, is 2·360; as compared with hydrogen it is 34 to 1.

Chlorine	1	36	52·9	1	
Oxygen	1	32	47·1	2	
	1	68	100·0	2	

Chloric Acid is a sour, colourless liquid; it reddens vegetable blues; the compounds of chloric acid, giving off oxygen with facility when heat is applied, promote the rapid deflagration of inflammable matter. It is decomposed by muriatic and sulphurous acids, and by sulphuretted hydrogen.

Chlorine	- 1	-	36	-	47·4	-	45
Oxygen	- 5	-	40	-	52·6	-	55
	1		76		100·0		100

This acid cannot exist independent, without water or some other base.

Perchloric Acid is a very stable compound, and is not decomposed by sulphuric or muriatic acid. Its specific gravity is 1·6, and it boils at 392°.

Chlorine	- 1	-	36	-	39·2	-	1·0
Oxygen	- 7	-	56	-	60·8	-	3·5
	1	-	92	-	100·0		

Hydrochloric or Muriatic Acid.—This gas is unrespirable, is inflammable, and has a strong attraction for water, which takes up 480 times its bulk of muriatic acid gas, and forms the liquid muriatic acid. Its specific gravity is 1·269, as compared with air. Muriatic acid gas consists of

Hydrogen	- 1	-	1	-	2·75	-	1
Chlorine	- 1	-	36	-	97·25	-	1
	1		37		100·00		2

Iodine has a bluish black colour, pungent odour, and acrid taste, melts at 227°, and is vaporised at 350°. Its vapour is of a fine purple colour. In a state of vapour 100 cubical inches weigh 264·75 grains. Its specific gravity, compared with air, is 8·7, and with hydrogen 125. It renders vegetable colour yellow.

Oxide of Iodine.— An alkali poured into its solution is rendered colourless.

Iodic acid; 1 of iodine and 5 of oxygen.

Bromine, at common temperatures and pressures, is a deep reddish-brown liquid, of a disagreeable odour; its specific gravity is 3°; 100 cubic inches of its vapour weigh 168 grains.

Bromic acid is sour, inodorous, first reddens, and then destroys the blue of litmus.

Bromine	- 1	-	78	-	66·1
Oxygen	- 5	-	40	-	33·9
	1		118		100·0

Fluorine is not found in an insulated state, but its equivalent number has been considered 16. It is a component of fluor spar, but supposed not to combine with either oxygen, chlorine, iodine, or bromine.

Fluor Spar is composed of one-third of fluoric acid and two-thirds of lime; fluoric acid dissolves silica, and corrodes glass.

Sulphur is a mineral product, and found crystallised and massive, most frequently in combination with iron, silver, lead, copper, &c. Its specific gravity varies from 1·970 to 2, or is twice the weight of water.

Sulphur is found in beds in the blue clay formation on the southern coast of Sicily, and in the gypsum of the salt deposits in Switzerland. The sulphurites and pyrites of the metals afford it in abundance. It begins to fuse at a temperature of 216°, and between 230° and 270° it is perfectly liquid; between 300° and 400° it becomes viscid, but regains its fluidity when cooled. It boils at 600°, and then sublimes into an orange-coloured vapour; when heated to 300° and poured into warm water, it acquires the consistency of soft wax, and hardens on cooling.

Sulphurous Acid, at common temperatures, is a gaseous body, obtained by burning sulphur in oxygen gas; its specific gravity is 2·22; 100 cubic inches weigh between 68 and 69 grains: its specific gravity, as compared with hydrogen, is as 32 to 1. This gas is one of those most easily condensed.

Sulphur	- 1	-	16	-	50
Oxygen	- 2	-	16	-	50
	1		32		100

This acid consists of 100 volumes of oxygen gas, and 16·6 of the vapour of sulphur, condensed into 100 volumes. It is gaseous, transparent, colourless, with a pungent and suffocating odour, and water absorbs about 33 times its volume.

Sulphuric Acid is a limpid, colourless, and inodorous liquid, and has great chemical powers, displacing most other acids; it is decomposed by several metals, which become oxidised, and evolve sulphurous acid. When the metals are dissolved in diluted sulphuric acid, the water only is decomposed, and the oxygen, being transferred to the metal, forms a metallic oxide, which unites with the sulphuric acid to form a *sulphate*, whilst the hydrogen is evolved. The specific gravity of sulphuric acid is 1·84. Liquid sulphuric acid is a compound of one atom of dry or anhydrous sulphuric acid, and one of water.

Anhydrous Sulphuric Acid.—When caustic lime or baryta is heated in its vapour they become ignited, and are converted into sulphates.

Sulphur	1	16	40
Oxygen	3	24	60
	1	40	100

The common or liquid sulphuric acid is composed of

Dry sulphuric acid	1	40	81
Water	1	9	19
	1	49	100

Sulphuretted Hydrogen Gas, under a pressure of seventeen atmospheres, at 50°, takes a liquid form; it has a peculiar fetid odour, and is so diffusible that a very small portion escaping is sufficient to be perceptible in a large space. Its specific gravity, as compared with air, is 1·17 to 1; and compared with hydrogen, as 17 to 1. 100 cubic inches weigh 86 grains.

Sulphur	1	16	94·1
Hydrogen	1	1	5·9
	1	17	100·0

The decomposition of the sulphurets is caused by exposure to the atmosphere; the oxygen combines with the metals to form an oxide, and the sulphur to form sulphuric acid.

Selenium is a brittle, solid, opaque body, of a metallic lustre, resembling lead in its aspect; it has a ruby colour; its specific gravity is 4·32; it becomes semi-fluid at a temperature of 212°, and boils at 650°.

Oxide of Selenium,—selenious oxide.

Selenium	1	40	83·3
Oxygen	1	8	16·7
	1	48	100·0

Selenious Acid.

Selenium	1	40	71·43
Oxygen	2	16	28·57
	1	56	100·00

Selenic Acid is a colourless liquid, which, at a temperature of 554°, is rapidly resolved into selenious acid and oxygen; it has a strong attraction for water, and when mixed with it evolves great heat.

Selenium	1	40	62·5
Oxygen	3	24	37·5
	1	64	100·0

Selenium combines with hydrogen, nitrogen, sulphur, and phosphorus.

Phosphorus is solid, semi-transparent, colourless, or of a light yellow tinge; it shines in the dark, and, when pure, its specific gravity is 1·770. It is insoluble in water, and out of the contact of air it melts at 105°.

Oxide of Phosphorus.

Phosphorus	3	48	85·78
Oxygen	1	8	14·22
	1	56	100·00

Phosphoric Acid consists of 44 of phosphorus and 56 of oxygen, and enters into the com-

position of several minerals, forming phosphates; its combining proportion is said to be 18. Phosphorus combines also with hydrogen and sulphur.

Carbon: of this the diamond is a specimen in its purest state, but it is usually found in charcoal, prepared from burnt wood; in ivory black, or animal charcoal; lamp black, or vegetable charcoal; or in plumbago, which is a compound of iron and charcoal. It is solid, black, porous and brittle, and when heated in air or oxygen produces carbonic acid. It is quite insoluble in water, and destroys the putrescent qualities of both animal and vegetable matters.

Carbon and Oxygen do not combine at common temperatures, though there are exceptions to this rule in organic bodies.

Carbonic Oxide (gaseous oxide of carbon).—The specific gravity of this gas, compared with hydrogen, is as 14 to 1, and to atmospheric air, as 0·972 to 1000, 100 cubic inches weighing 30·2 grains; when burnt with oxygen it produces carbonic acid.

Carbon	1	6	42·9
Oxygen	1	8	57·1
	1	14	100·0

Carbonic Acid (*fixed air*) is gaseous, transparent, and colourless, and absorbed by an equal bulk of water; it is found to exist in a vast number of minerals, as a *Carbonate*, where it is united as a salifiable base, and particularly in lime, magnesia, &c.; it is contained in mineral waters and the atmosphere, and is distributed throughout the globe. Its specific gravity is about 1·52, and from its density it may be poured out of one vessel into another. As compared with hydrogen it is as 22 to 1; and 100 cubic inches weigh 47·25 grains, and when subjected to great pressure it becomes liquid, and is then limpid, colourless, and extremely fluid; it has been obtained in a solid form.

Carbon	1	6	27·27
Oxygen	2	16	72·73
	1	22	100·00

Carbonic acid unites with ammonia, chlorine, iodine, bromine, and hydrogen, and with the latter forms the several important compounds called the hydrocarbons and hydrocarburets.

Carburetted Hydrogen, or fire-damp, is a species of hydrocarbon, found in the cavities of coal mines, in stagnant pools of water, produced by the decomposition of vegetable matter; the specific gravity of this gas is 0·555, and compared with hydrogen it is as 8 to 1; 100 cubic inches weigh from 16 to 17 grains; 100 volumes of this gas require 200 of oxygen for its perfect combustion, the result of which is water and 100 volumes of carbonic acid.

Boron is a deep olive-coloured substance, insoluble in water and infusible; its specific gravity is about 2. Neither air nor water act upon it, but when heated to redness it takes fire, and burns into boracic acid.

Boracic acid is found native among volcanic products, and also in borax.

Boron	1	20	29·41
Oxygen	6	48	70·59
	1	68	100·00

Fluoride of Boron has a specific gravity of 2·371, and water takes up about 700 times its volume of this gas.

Boron	1	20	16
Fluorine	6	108	84
	1	128	100

Potassium is a white metal of great lustre, but soon loses its brightness by exposure to the air, and is converted into an oxide. Its attraction for oxygen exceeds that of all other bodies, and in consequence it is the most powerful de-oxidising agent we possess; at ordinary temperatures it is solid, but becomes partially fluid at 50°, and completely so at 150°; it is lighter than water, and for a moment floats upon it, but soon after its contact it becomes inflamed.

Protoxide of Potassium, or Potassa, is found combined with many of the earthy minerals, and particularly with mica and felspar

Potassium	1	40	83·34
Oxygen	1	8	16·66
	1	48	100·00

Peroxide of Potassium :—

Potassium	1	40	62·4
Oxygen	3	24	37.6
	1	64	100·0

Potassium combines with chlorine, iodine, bromine, hydrogen, and nitric acid to form

Nitrate of Potassa. — *Saltpetre* is an abundant mineral production, being found in many soils, and particularly in old plaster rubbish, which sometimes, after washing, affords 5 per cent. of this product; it is also found in situations where animal or vegetable matter has been left in a putrefied state in contact with calcareous soils. Upon newly-built walls it sometimes shows itself, and is the result probably of the mortar containing hair, or other animal matter. Mortar made of lime, wood-ashes, and cow-dung produces in a short time efflorescent nitre.

Oxygen	6	48	47·10
Nitrogen	1	14	13·75
Potassium	1	40	39·15
	1	102	100·00

Gunpowder is a mixture of nitre, sulphur, and charcoal in the following proportions :—

	Common.	Shooting Powder.	Shooting.	Miners' Powder.
Saltpetre	75	78	76	65
Charcoal	12·5	12	15	15
Sulphur	12·5	10	9	20

Potassium unites with sulphur, selenium, carbon, cyanogen, and boron.

Sodium is soft and malleable, and its globules may be welded together by pressure; in colour it resembles silver, but soon has its lustre changed by exposure to the air; it fuses at 190°, and becomes volatile at a white heat; its specific gravity is 0·9348; when thrown into water hydrogen is given out, and the metal rapidly oxidises.

Sodium and Oxygen. — Soda.

Sodium	1	24	75
Oxygen	1	8	25
	1	32	100

Peroxide of Sodium.

Sodium	1	24	66·7
Oxygen	1½	12	33·3
	1	36	100·0

Chloride of Sodium. — Common salt exists as a fossil, and is found abundantly in solution. It is taken up nearly in the same quantities both by hot and cold water; in solution it deposits crystals during evaporation, though it does not do so by cooling; 100 parts of water at 58° dissolve 36 of salt.

Common Salt is the source of soda, muriatic acid, and chlorine.

Sodium	1	24	40
Chlorine	1	36	60
	1	60	100

Chloride of Soda is a powerful bleaching agent; when exposed to the air it absorbs carbonic acid, and evolves chlorine, which occasions it to be used as a disinfectant.

Soda and Nitric Acid. — Nitrate of soda resembles common nitre; it is found native in Peru, forming a stratum of many miles in extent, covered with clay and alluvium.

Soda	1	32	37·2
Nitric acid	1	54	62·8
	1	86	100·0

Sulphuret of Sodium is composed of

Sodium	1	24	60
Sulphur	1	16	40
	1	40	100

Sulphate of Soda.— Glauber's salt is a natural product present in many mineral waters.

Dry sulphate of soda	1	72	44·4
Water	10	90	55·6
	1	162	100·0

Carbonate of Soda is a very important salt, obtained by burning sea plants, the ashes of which produce the alkali called soda. Its specific gravity in the crystalline form is 1·62; it is soluble in twice its weight of water at 60°, and in less than its own weight at 212°.

Soda	1	32	22·25
Carbonic acid	1	22	15·25
Water	10	90	62·50
	1	144	100·00

It is manufactured in large quantities by heating carbonate of lime, charcoal, and sulphate of soda, the charcoal tending to produce sulphuret of sodium, and the lime to remove sulphur or sulphuric acid. The carbonic acid of the carbonate of lime, and that from the flame of the furnace, being made to pass over the soda, give it the carbonic acid. It is then crystallised.

Borate of Soda, Borax, is soluble in 20 parts of water at 60°, and in six parts of boiling water; at a red heat it forms a transparent glass, which by exposure to the air becomes opaque: the anhydrous borax consists of

Soda	1	32	31·4
Boracic acid	1	68	68·6
	1	100	100·0

Crystallised borax.

Soda	1	32	16·85
Boracic acid	1	68	35·80
Water	10	90	47·35
	1	190	100·00

Lithium, when first discovered, was supposed to be soda, but differs from it, and has peculiar properties. Lithia, or protoxide of lithium, is not very soluble in water, and converts vegetable blues green.

Barium is metallic and of a dark grey colour, heavier than water, and attracts oxygen with great rapidity. Its specific gravity is 2°, and when gently heated, burns with a red light.

Oxide of Barium, Baryta, is the heaviest of all the earths, its specific gravity being 4, and in all its leading properties bears a strong resemblance to lime. It is poisonous, as are all its compounds. Carbonic acid has a much greater attraction for baryta than for lime.

Barium	1	69	89·6
Oxygen	1	8	10·4
	1	77	100·0

Nitrate of Baryta is composed of

Barium	1	77	58·7
Nitric acid	1	54	41·3
	1	131	100·0

Sulphate of Baryta, or Heavy Spar, is found in great abundance in nature; when heated it decrepitates, and at a very high temperature is fused into a white enamel. It is harder than carbonate of lime, but not so hard as fluor spar. Its specific gravity is 4·7.

Sulphate of baryta in an anhydrous state consists of

Baryta	1	77	63·8
Sulphuric acid	1	40	34·2
	1	117	100·0

Carbonate of Baryta is also poisonous.

Baryta	1	77	77·7
Carbonic acid	1	22	22·3
	1	99	100·0

Strontium is nearly as heavy as barium, and is a substance of rare occurrence.

Protoxide of Strontium, Strontia, is a substance of a greyish colour, is distinguishable from lime by the insolubility of the sulphate; it is extremely infusible, but is less caustic than the fixed alkalies and baryta.

Strontium	1	44	84·6
Oxygen	1	8	15·4
	1	52	100·0

Calcium has a white colour and a metallic lustre; when heated in the air, it is oxidated and converted into lime.

Calcium and Oxygen—Oxide of Calcium—Quick Lime, is extremely infusible, but gives out a brilliant light when intensely heated; pure lime is of a pale grey tint, and has a specific gravity of 2·3.

Calcium	1	20	71·4
Oxygen	1	8	28·6
	1	28	100·0

Hydrate of Lime—Slaked Lime, is a compound of

Lime	1	28	75·6
Water	1	9	24·4
	1	37	100·0

Nitrate of Lime is formed by neutralising nitric acid, diluted with water, by lime; is found in old plaster, and in mortar: in the anhydrous state it consists of

Lime	1	28	34·1
Nitric acid	1	54	65·9
	1	82	100·0

Sulphuret of Calcium is soluble in water.

Calcium	1	20
Sulphur	1	16
	1	36

Sulphate of Lime is found abundantly under the form of gypsum, selenite, alabaster, &c. all of which contain water of crystallisation, which is driven off before it can be made into plaster of Paris. It is soluble in 500 parts of cold water, and more so in boiling water, hard water being produced. Anhydrous sulphate of lime consists of

Lime	1	28	41·1
Sulphuric acid	1	40	58·9
	1	68	100·0

The crystallised sulphate of lime consists of

Anhydrous sulphate of lime	1	68	79
Water	2	18	21
	1	86	100

Native sulphate of lime or selenite is crystallised: the fibrous and earthy is called gypsum, and the granular or massive alabaster; the variety called satin gypsum is used for ornamental purposes. Massive and granular gypsum is applied to architecture.

Marbre de Bergamo is a variety of sulphate of lime, called anhydrous gypsum, which sometimes contains common salt.

Chloride of lime, or bleaching powder, destroys vegetable and animal colouring matters, and various effluvia. It is a dry white powder, smells of chlorine, and has an acrid taste: when exposed to the air it absorbs carbonic acid, and evolves chlorine. It probably consists of a chloride of lime, containing one proportion of chlorine and one of lime, with a proportion of hydrate of lime.

Carbonate of Lime.—Heat expels the carbonic acid, whilst muriatic and the other acids decompose it; it is the most abundant compound of the globe.

Lime	1	28	56
Carbonic acid	1	22	44
	1	50	100

It occurs native in various forms, and in the Iceland spar is extremely pure and trans-

parent. White granular limestone, or primitive marble, is another variety; and among the inferior limestones are several, as the oolite, common limestone, &c.

Magnesium fuses at a red heat, then burns, uniting with the oxygen of the air to form magnesia.

Oxide of magnesium, or magnesia, consists of—

Magnesium	1	12	59·3
Oxygen	1	8	40·7
	1	20	100·

Its specific gravity is 2·3, it is almost infusible, and nearly insoluble in water.

Aluminum is difficult of fusion, requiring a higher temperature to melt it than cast-iron, and it is not oxidised by exposure to the air; water at a common temperature does not act upon it, nor is it affected by nitric or sulphuric acids; but in hot sulphuric acid it rapidly dissolves, and sulphurous acid is evolved. Sir Humphry Davy found that potassa was formed by passing the vapour of potassium over alumina at a white heat.

When chloride of aluminum mixed with potassium is heated in a platinum crucible by means of a spirit lamp, and the substances begin to act, the temperature rises suddenly to rednets, and then care must be had that the chloride does not pass off in an undecomposed state, or that there is an excess of alkali in the residue. After the whole is cooled down, and washed with cold water, pure aluminum is found in the state of finely divided grey substance, with a small degree of metallic lustre. Aluminous rocks are abundant in every formation.

Oxide of Aluminum.—Alumina is an insipid and insoluble compound, with a specific gravity of 2. It has a strong attraction for moisture, and will absorb about one-third of its own weight, which may be again expelled by ignition. Alumina is rendered plastic when mixed with water, and has a strong affinity for various organic compounds; and moist alumina is readily soluble in most of the acids. When ammonia is put to a solution of alum, in infusion of cochineal or madder, the aluminous earth is precipitated with the red colouring matter, and in this way the colour lake is formed. Alumina is known by its solubility in caustic potassa, and by its octohedral crystals of alum, which are formed on evaporating the sulphuric solution, with the addition of sulphate of potassa, and by the blue colour which it has when moistened with nitrate of cobalt strongly heated. Alumina does not combine with carbonic acid, but with other acids and the alkalies, and with the latter its compounds are soluble in water.

The different hydrates of alumina are found in a native state, though their distinct atomic compounds are not yet ascertained. Alumina as a protoxide may be thus stated—

Aluminum	1	10	55·5
Oxygen	1	8	44·5
	1	18	100·0

Many chemists, however, consider its proportions to consist of two equivalents of alumina and three of oxygen.

Alumina exists in all kinds of clay, and from an analysis made by Professor Faraday of the blue alluvial clay of the Medway, in its dark-coloured and moist state, it was found that 100 parts whose specific gravity was 1·46, contained—

Water	50·9
Sand	14
Finer particles { Silica	14·8
Finer particles { Alumina	10·8
Peroxide of iron	3·4
Carbonate of Lime	1·5
Fragments of wood	1·5
Organic matter	3·1
	100·0

In the brown pit clay of Upner, he also found, its specific gravity being 2·07,

Water	19
Sand	30·5
Finer particles { Silica	29·8
Finer particles { Alumina	16·5
Peroxide of iron	3·7
Carbonate of lime	·5
	100·0

Berthier has given a table of the compositions of various clays, and among them, that at Stourbridge, which contains —

Silica	·637
Alumina	·207
Oxide of iron	·040
Water	·103
	·987

And those met with in the county of Devonshire, used for pottery, —

Silica	·496
Alumina	·374
Water	·112
	·982

Clay in general may be considered as a silicate of alumina, or a compound of silica, alumina, and water; and the best for pottery are those where the proportions are three of silica to one of alumina, or by weight 48 to 18.

Sulphate of Alumina and Potassa, or common alum, consists of three equivalents of sulphate of alumina, one of sulphate of potassa, and twenty-five of water; its crystals are octohedrous. Aluminous slate, which is an argillaceous slaty rock, containing sulphuret of iron, when roasted so as to oxidise the iron and acidify the sulphur, produces a sulphate of alumina, and when to this sulphate of potassa is added, alum is obtained.

Alum reddens vegetable blues, and dissolves in five parts of cold water, and in rather more of its own weight in boiling water: in its crystallised state it consists of —

Sulphate of alumina	3	174	35·73
Sulphate of potassa	1	88	18·07
Water	25	225	46·20
	1	487	100·

Silicium is a simple non-metallic combustible, and has a strong resemblance to boron. It may be perfectly oxidised, and converted into silica or silicic acid by mixing it with dry carbonate of potassa, and heating it to redness, when a silicate of potassa is obtained.

Silica is the most common, as well as the most abundant, of the earths; it constitutes the chief portion of hard stones and minerals. It is found in solution in many springs, but the water must be raised to a high temperature before it will hold any quantity in solution; and retaining a greater heat under the pressure of the sea than in the atmosphere, submarine springs are probably more charged with silex than those to which we have access.

The waters of Ireland hold silex in solution in consequence of the presence of the alkali soda. The deposition of silica in an insoluble state is from the water, when cooled down, not being so able to retain it as at a high temperature, — the evaporation of the water decomposing the compounds of silica and soda which at first existed. Fragments of wood and plants are often found completely silicified, or converted into stone, called petrifactions.

Oxide of Silica, Silica, or Silicic Acid. — It exists nearly pure in flint, and quite so in rock crystal; it is a white powder, insoluble in water, and infusible except by intense heat; its specific gravity is 2·66.

Silicium	1	8	50
Oxygen	1	8	50
	1	16	100

Fluo-silicic acid (*Fluoride of Silicium*). — The only acid body which acts energetically on silica is the hydrofluoric acid; it is gaseous, transparent, and colourless. Water condenses 365 times its volume; its specific gravity is 3·61 compared with air; 100 cubic inches of the gas weigh 112 grains: —

Silicium	1	8	30·8
Fluorine	1	18	69·2
	1	26	100·0

Silicate of Potassa. — To obtain this compound silica is generally fused with the carbonate of potassa, the carbonic acid being expelled by the heat; with 3 of carbonate of potassa and 1 of silica, a glass is formed which is soluble in water; if there is an excess of silica, it is insoluble. Plate glass is made from soda and siliceous matter. Common flint glass contains 50 of silica, 34 of the oxide of lead, and 14 of potassa.

Yttrium, Glucinum, Zirconium, Thorinium, are all extremely rare metals.

Antimony is found native, and its principal ore is the sulphuret; the most common is crystallised into four and six-sided prisms; it is of a white colour, brittle, and of a crystalline texture; fuses at about 800°, and its specific gravity is 6·712; it is prepared from the sulphuret by heating it in a crucible with iron filings, when a sulphuret of iron and the metallic antimony are formed.

The composition of the oxides has been differently stated, and it seems that there are three distinct varieties. The oxygen in the protoxide is to that of the peroxide as 1·5 to 2·5, and that in the three oxides one atom of antimony is united with 1·5, 2, and 2·5 of oxygen.

Sulphuret of antimony is artificially produced by fusing the metal with sulphur; it has a dark grey metallic colour, and a specific gravity of 4·36.

Antimony	1	65	73
Sulphur	1½	24	27
	1	89	100

Bismuth is found native, combined with oxygen, arsenic, and sulphur; it occurs crystallised into cubes and octohedra; it is a brittle white metal with a reddish tint; its specific gravity is 9·85; it is fusible at 496°, and always crystallises when cooling.

Protoxide of bismuth is obtained by dissolving bismuth in nitric acid, which is precipitated by dilution with water, and heated, when dry, to a dull redness.

Bismuth	1	72	90
Oxygen	1	8	10
	1	80	100

Chloride of Bismuth, or *Butter of Bismuth*, is of a grey colour, and fuses at 480°; when exposed to air it deliquesces.

Bismuth	1	72	66·6
Chlorine	1	36	33·4
	1	108	100·0

Alloys of bismuth are formed with gold, platinum, and silver. Fusible metal is a compound of 8 of bismuth, 5 of lead, and 3 of tin, which liquefies at the temperature of boiling water. Soft solders contain bismuth.

Manganese has a powerful affinity for oxygen, attracting it from air and water; in its appearance it resembles iron. It is a hard grey metal, brittle and granular; the specific gravity of which is 6·8.

Oxide or Protoxide of Manganese: —

Manganese	1	28	77·75
Oxygen	1	8	22·25
	1	36	100·00

Manganesic Acid. — When peroxide of manganese (which is 1 of manganese and 2 of oxygen) and nitre are heated, a compound is obtained called Chamelion. It consists of manganesious acid and potassa, gives in water a green-coloured solution, which becomes purple and red by exposure to the air; the red colour is formed by the manganesious compound attracting oxygen.

Chromium. — In a metallic state its colour resembles that of iron; it is brittle, difficult of fusion, and is not easily acted upon by the acids. Its specific gravity is 6.

Protoxide of Chromium is of a green colour, and when fused with borax produces that used in porcelain and enamel painting; the emerald receives its tint from it.

Chromium	1	28	70
Oxygen	1½	12	30
	1	40	100

Chromate of Lead, in its native state, is of a deep orange colour, approaching to redness, but when reduced to a fine powder is yellow; its primitive crystal is an oblique prism. Its specific gravity is 6. In an anhydrous state it consists of

Oxide of lead	1	112	68·29
Chromic acid	1	52	31·71
	1	164	100·00

The Dichromate of Lead, which contains two of oxide of lead and one of chromic acid, forms valuable pigments, used in oil and water-colours, dyeing, &c.

Chromic Acid, which is a compound containing three of oxygen, combines with potassa, mercury, silver, chlorine, fluorine, &c.

Cobalt. — This mineral is of a grey colour with a reddish tint, is very heavy and brittle. It is found native, combined with iron, nickel, arsenic, sulphur, &c. Its specific gravity is 8·5, and it is used to give a blue colour to glass; it crystallises into cubes, octohedrons, and dodecahedrons.

Oxide of Cobalt, or protoxide, is obtained by heating the carbonate of cobalt out of the contact of air; it is of a greenish grey colour, and imparts a blue tint to glass and enamel.

Cobalt	1	30	78·9
Oxygen	1	8	21·1
	1	38	100·0

Smalt is a blue-coloured vitreous compound, produced by fusing zaffre, which is an impure oxide which remains after the arseniuret of cobalt has been heated to expel the arsenic, the cobalt becoming oxidated; this is mixed with twice its weight of finely-powdered flint. Smalt and azure blue are formed by fusing zaffre with glass, which in a hot state is dropped into water, and afterwards reduced to a fine powder.

Arsenic is of steel grey colour, brilliant lustre, crystalline texture, brittle, and soon tarnishes on exposure to the air. Its specific gravity is 5·8, and it is readily volatilised at a temperature of 360°; and when exposed freely to the air produces arsenious acid.

Arsenious Acid (white arsenic). — It is white, semi-transparent, brittle, and becomes opaque by exposure to the air; it condenses into small octohedral crystals. It is soluble in sixteen of water at a temperature of 212°, a portion being again deposited in crystals as the solution cools. It is nearly tasteless, but highly poisonous. When arsenious acid is slowly sublimed, octohedral and tetrahedral crystals are formed, derived from a rhombic prism.

Arsenic	1	38	76
Oxygen	1½	12	24
	1	50	100

The arsenious acid combines with bases and forms the

Arsenites. — Those of potassa and soda are easily soluble and uncrystallisable; those of lime, strontia, baryta, and magnesia, are more difficult.

Scheele's Green, a fine apple-green colour and used as a pigment, is a mixture of this acid with a solution of sulphate of copper. With lead, antimony, and bismuth, white precipitates are formed.

Nickel is a brilliant white metal, both ductile and malleable, and not oxidised by exposure to the air or moisture at common temperatures. Its specific gravity is 8·5.

Protoxide of Nickel consists of

Nickel	1	28	77·77
Oxygen	1	8	22·23
	1	36	100·00

Nickel combines with chlorine, iodine, fluorine, sulphur, &c.

Meteoric Stones have a black surface, when broken exhibit a coarse texture and a grey colour; they are compounds of silica, magnesia, iron, and nickel.

Mercury has much the same colour and brilliancy as silver; it is liquid, forms round globules, which when brought in contact readily unite together; exposed to the air it quickly tarnishes; at 40° it loses its liquid state, and becomes solid and malleable, and in the frozen state its specific gravity is 15·6. At a temperature of 670° it boils, and becomes vapour; at 60° its specific gravity is 13·5.

Native Cinnabar is the principal ore of mercury, and occurs massive and crystallised in six-sided prisms, rhombs and octohedra. It is sometimes of a steel grey, and at others a bright red colour; it is a bi-sulphuret of mercury.

Oxide or Protoxide of Mercury is insoluble in water and muriatic acid, but is dissolved by acetic acid.

Mercury	1	200	96·1
Oxygen	1	8	3·9
	1	208	100·0

Mercury combines with chlorine in two proportions.

Protochloride of Mercury, or Calomel—

Mercury	1	200	84·74
Chlorine	1	36	15·36
	1	236	100·00

Perchloride of Mercury, or Corrosive Sublimate, has an acrid nauseous taste; its specific gravity is 5·2. It is soluble in twenty parts of water at a temperature of 60°; boiling water takes up about half its weight, and as it cools quadrangular prismatic crystals are formed. It dissolves without decomposition in muriatic acid, but is insoluble in concentrated nitric and sulphuric acids.

Mercury	1	200	73·53
Chlorine	2	72	26·47
	1	272	100·00

Bisulphuret of Mercury, Cinnabar, or Vermilion, may be manufactured by mixing 8 parts of mercury in an iron pot with 1 of sulphur, and combining them at a moderate heat; this is put into a glass subliming vessel, and heated in a sand-bath to redness, after which it is rubbed down into a fine powder.

Mercury	1	200	86·2
Sulphur	2	32	13·8
	1	232	100·0

Silver occurs native, and crystallised in cubes and octohedra; pure it has a brilliant white colour, and when polished a bright lustre, is extremely ductile and malleable. At a bright red heat it melts, and when pure absorbs oxygen, which as it cools it again evolves. The tarnish of silver is produced by the vapours of sulphur, and it is most apparent when the metal is alloyed with copper.

When the argentiferous sulphuret of lead is placed in the reverberatory furnace, and a current of air suffered to pass over its surface, the lead is converted into litharge, and the silver is left in the metallic state.

The sulphurets of silver are reduced by amalgamation; when these ores are washed and ground, they are mixed with common salt, and roasted; sulphate of soda and chloride of silver are thus formed; it is then reduced to a fine powder, and agitated with mercury, water, and iron filings; thus the chloride of silver is decomposed, and the chloride of iron being washed away, the silver and mercury combine into an amalgam, when the mercury is partly pressed out, and the remainder driven off by distillation; the specific gravity of silver is 10·5.

Oxide of Silver is of a dark olive hue, and when employed in glass or enamel painting, gives a yellow colour.

Silver	1	108	93·103
Oxygen	1	8	6·897
	1	116	100·000

Chloride of Silver is formed by adding to a solution of chlorine of muriatic acid or common salt a solution of nitrate of silver; it is precipitated in the form of a heavy powder, of a white colour, which by exposure to light becomes black.

Silver	1	108	75
Chlorine	1	36	25
	1	144	100

When found native, it is crystallised in cubes and octohedra.

Nitrate of Silver.—Silver is readily dissolved with nitric acid, when diluted with three parts of water. Nitrate of silver should be a clear and colourless solution; by exposure to light it becomes deep purple, and all animal substances, when tinged with it, are of a deep yellow colour. Ivory, marble, and other substances when soaked in this solution, and afterwards exposed to a strong light, become black.

Nitrate of silver is an anhydrous salt, and consists of

Oxide of silver	1	116	68·23
Nitric acid	1	54	31·77
	1	170	100·00

Alloys of Silver.—The standard silver consists of 11·10 silver and 6·90 copper. Amalgam of silver is used for plating; when applied to copper, the mercury is evaporated by heat,

and afterwards the silver is burnished. A plate of silver is sometimes applied to a plate of copper, and beaten or drawn out. Brass is silvered by a mixture of chloride of silver, chalk, and pearlash; when the metal is thoroughly cleaned, the above mixture, moistened with water, is rubbed over it: clock dials and scales for thermometers are silvered in this manner.

Gold is found native and in a metallic state; it is either massive or crystallised in cubes and octohedra; it melts at a bright red heat, 2016°, and when fused is of a brilliant green colour; its specific gravity is 19·3. It is the most malleable and ductile of the metals, and is not tarnished or affected by the action of either air or moisture. It is separated from copper by cupellation, and from silver by nitric or sulphuric acids. Gold is so malleable that it may be beaten into leaves two hundred and eighty-two thousandths of an inch in thickness, and a grain of it may be made to cover 56 inches of surface; its ductility is so great, that the same quantity may be drawn out into 500 feet in length.

The Protoxide of Gold consists of

Gold	1	200	96·25
Oxygen	1	8	3·75
	1	208	100·00

The Peroxide consists of

Gold	1	200	89·5
Oxygen	3	24	10·5
	1	224	100·0

The Perchloride of Gold is decomposable at a red heat, and is soluble in water, alcohol and sulphuric ether; the latter solution is used for gilding. The aqueous solution, or muriate of gold, is decomposed by several vegetable acids.

Protochloride of tin, added to a dilute solution of chloride of gold, occasions a change of colour; the purple powder produced from the compound is used in enamel and glass painting to produce a fine red colour.

Gold	1	200	65
Chlorine	3	108	35
	1	308	100

Platinum resembles silver, but has a less brilliant lustre; it is dissolved by chlorine and nitro-muriatic acid; its affinity for oxygen is extremely feeble; its specific gravity is 21·5. In a minute state of division it promotes the union of the hydrogen and oxygen gases, absorbing them in large quantities.

Protoxide of Platinum.

Platinum	1	96	92·31
Oxygen	1	8	7·69
	1	104	100·00

Palladium, *Rhodium*, *Osmium*, and *Iridium*, have all been obtained from the ores of platinum; but they have not perhaps been either of them perfectly examined.

Having described the composition of several minerals that compose the earth's crust, it is necessary to examine somewhat more in detail the methods adopted in extracting the ores of lead, iron, copper, and tin, and their conversion into a state to render them useful to the engineer. The report of the commissioners appointed to examine the mines, published in 1842, affords information of a highly interesting character, and which we have taken chiefly for our guide upon this subject.

Lead is seldom or ever found in a pure state, but in combination with carbonic, sulphuric, phosphoric, arsenic, chromic, and other acids, together with oxygen and chlorine. It has a colour of a bluish white, is flexible and soft, melts at a temperature of 612°, and when air is admitted freely with heat it is converted into an oxide. At common temperatures air and water act slowly upon it; its specific gravity is 11·4.

Oxides of Lead. — When air or water is charged with carbonic or other acids, they will oxidate lead; if the acid be either phosphoric, arsenic, sulphuric, or the hydriodic, an insoluble crust is formed on the surface of the lead, which protects it, and water may be retained in a cistern or pipes made of it with perfect safety. Carbonic acid in abundance forms a carbonate, which, instead of encrusting the lead, mixes in a minute state of division with the water, and is highly poisonous.

Protoxide of Lead, Massicot, or yellow lead, is insoluble, fusible at a red heat, and combines with many earthy and saline substances; when heated with charcoal it is decomposed,

metallic lead being obtained. At a high red heat it fuses, and forms what is termed litharge, which is a lamellar vitreous mass of reddish brown colour.

Lead	1	104	92·857
Oxygen	1	8	7·143
	1	112	100·000

Deutoxide of Lead, Red Lead, Minium, is a common red pigment, produced by exposing the protoxide to the action of heat at 700°, and air sufficient to oxidise without fusing it; its fine red colour loses its brilliancy by exposure to light.

Lead	1	104	89·66
Oxygen	1½	12	10·34
	1	116	100·00

Peroxide of Lead.—Lead 104 with oxygen 16 = 120.

Chloride of Lead is obtained by heating laminated lead in chlorine; the gas is absorbed, and chloride of lead is formed; its specific gravity is 5·13.

Patent Yellow is formed from the compound of chloride and oxide of lead.

Lead	1	104	74·3
Chlorine	1	36	25·7
	1	140	100·0

Sulphuret of Lead, the galena of mineralogists, is found native, and is the chief source whence pure lead is obtained; its primitive form is that of the cube; it often contains a sufficient quantity of silver to be worth extracting. Galena is reduced by a simple process; the ore is broken and washed, then roasted in a reverberatory furnace, the temperature being sufficient to soften but not to fuse it. When the fumes of the sulphur are driven off it is then fused; the lead sinks to the bottom of the fuel which has reduced it, and is run out and moulded into pigs. Sulphuret of lead has a colour and lustre resembling pure lead; it is brittle, and requires a white heat for fusion; its specific gravity is 7·58.

Lead	1	104	86·66
Sulphur	1	16	13·34
	1	120	100·00

Sulphate of Lead in its native state is crystallised into prisms and octohedra.

Oxide of lead	1	112	73·68
Sulphuric acid	1	40	26·32
	1	152	100·00

Carbonate of Lead, White Lead, or Ceruse, is prepared by exposing sheet lead to the action of the vapour of vinegar, or by decomposing the acetate of lead by a carbonate; its specific gravity is 6·4: when found native it is one of the most beautiful of metallic ores; it is soft and brittle, sometimes tinged with carbonate of copper, and has a green colour; its primitive form is the octohedron, though it is found prismatic and tabular.

Oxide of lead	1	112	83·58
Carbonic acid	1	22	16·42
	1	134	100·00

Alloys of Lead.—*Plumber's Solder* contains equal parts of lead and tin, or, according to others, two of lead and one of tin. Mirrors are made in Sweden containing 0·39 of lead, and 61 of tin. Common pewter consists of 80 parts of tin and 20 of lead.

Of the Mines that produce Lead—Northumberland, Durham, and Cumberland. This country, although politically distributed amongst the three counties, is one and the same in all its characteristic features. From it flow the Tyne, the Wear, and the Tees, and many branches which fall into these rivers. Along their banks are dales or valleys highly cultivated, but beyond them rise dark fells, covered with peat moss and heath, and between one vale and another is a wide range of high moorland, extending sometimes for many miles. In these upland districts are no inhabitants; thousands of black-faced sheep are scattered over them, and grouse are found in abundance.

The rivers do not, as in rich, flat, clayey lands, form for themselves a winding serpentine course, but flow onward in a straight line, and with a rapid current. The channel, of

which the water occupies but a small portion in dry weather, is covered with boulders, some of an hundred weight, and small pebbles, and here and there an accumulation of sand. After rain, and in winter, the stream flows in a powerful flood. At short distances, on both sides of the rivers, are vales or gullets, with the banks feathered with wood, through which, with thundering noise, the smaller streams, called *Burns*, rush over the stones to join the great stream below. These deep fissures are of importance, as they often lay open to view veins of ore, and direct the operations of the miner to the places where it is met with in sufficient plenty to reward his toil.

Weardale is held by many to be the most beautiful of these vales. It gradually contracts into narrower spaces, and the hills become loftier on proceeding westward from the low country; it is 15 miles in length, and considered to commence about 3 miles below the village of Stanhope, where the grass lands are interspersed with fields of wheat, oats, and turnips, the soil being fertile, and the crops abundant; there is much woodland, but gradually, as we ascend, this is less frequent; for some miles there is a considerable show of trees by the river banks, and thick plantations on the sides of the ravines, through which, over rocks and stones, the burns dash downwards: towards the upper part of the dale the trees are solitary, near habitations, or occasionally on the river-side. Beyond is Wearhead, a hamlet where two burns meet, and which give a name to the Wear; each rises a mile or two higher up to the centre of a wild, treeless, heath-covered hollow in the mountain.

Both sides of the dale, for ¾ mile, back from the river at Wearhead, and still farther down are clothed with the most beautiful green and rich vegetation. The whole of the dale is well inclosed with stone fences, and subdivided into holdings of about 5 acres each. Houses are distributed on both sides of the river, and form a continuous scattered village: these houses, built of blocks of stratified hard sandstone, are covered with slate, and as lime is abundant, they are whitewashed, and present a clean, neat appearance, with *the fronts towards the sun*. Here and there is a little hamlet by the road-side, the residence of tradesmen, to whose stores and workshops the population of both sides of the vale resort. There is much travelling backwards and forwards along the road, but seldom do the inhabitants of the dale pass far beyond its bounds. They see few but themselves, and intermarry, so that, by nearer or more remote relationship and affinity, they constitute but one great family, and an attachment subsists between them which nothing can overcome: hence it is that, although by removing only 20 miles lower down, into the coal country, a young man might nearly double his income, and have the prospect of adding many years of health and strength to his life, he will not remove. He clings to his beloved dale, and follows an occupation which in most instances allows but a short life, the last years of which are spent in sickness and in sorrow; and this, too, is the effect on a population well educated, and of intellectual capacity and acquirement surpassing any met with elsewhere in England.

The river Tees rises in a hollow, near the foot of Cross Fell, and is soon augmented by other mountain torrents; for many miles it flows through a desolate valley, with a little grass land on each side, a few houses, with only now and then a solitary tree; gradually the vale widens, and for 3 or 4 miles before arriving at Middleton-in-Teesdale it is well adorned with wood. On the Yorkshire side the rude hills approach very near the river, and in some places present lofty cliffs. Middleton is a pleasant village, embosomed in woods, with the Tees flowing on its south side, and the Yorkshire hills receding for several miles. Below Middleton, and down to Barnard Castle, the country is beautiful, and the grass lands are interspersed with fields of grain.

From Stanhope it is ten miles in a northerly direction to the mines and washing-floors on the Derwent. A turnpike road, then one made by the parish of Stanhope, and another by that of Edmondbyers, conducts to the parish of Hunstonworth. The fell is altogether uninhabited, and it may be stated as a proof of the severity of the climate in winter, that there are high posts of wood painted *white*, with the top *black*, to enable the traveller to find his way amidst the snow.

The Vale of the Derwent, near the works of the Derwent Company, is not 100 yards wide; the miners and washers come from a distance, and for a time remain in the lodging shops provided for their use.

The upper part of West and East Allendale, where the mines and washing-floors are situate, are wild, narrow vales, inclosed within lofty dark fells. From Weardale to Alston Moor the road lies over a high uncultivated dreary tract, which conducts to the busy village of Nenthead, with its smelting mills and washing floors, on which may usually be seen a multitude of children engaged at work. The little river Nent flows five miles to the town of Alston Moor, through a narrow vale, divided into small holdings, and studded with houses like Weardale, but with very little wood.

The town of Alston is situated on the side of a hill close to the river Tyne, beautifully surrounded with wood. The vale of the Tyne below the town is richly cultivated, and ascends for about five miles between lofty hills, where the river rises in a hollow at the foot

of Cross Fell, which lofty mountain on the south, and others on the west, give an interesting grandeur to the prospect from every place in the vicinity of Alston.

The whole of the lead country possesses great beauty, though of a diversified character. Mining is the sole resource of the inhabitants, who are universally so attached to the country, and to each other, that they continue to engage in an employment which ill remunerates their toil, and brings many of them to an untimely grave.

The Lead Country, in a geological sense, is below the coal measures and above the old red sandstone; the former consists of many strata of siliceous sandstone, limestone, clay, shale, with beds of indurated clay between them. The lead is found in all these strata, though not often in clay or in clay-shale, and a vein will descend from the surface down through all the strata, until it is so deep that it can no longer be followed on account of water and other difficulties. Amongst the most remarkable beds is the encrinital limestone, with abundance of its peculiar fossil remains; it may be seen in the bottom of a large burn which falls into the Wear, some miles below Stanhope, near Frosterly Bridge, at Bishop's Crag. Limestone boulders gathered from the bed of the Wear supply the lime-kilns; and there are large quarries worked about two miles below Stanhope, and near the commencement of the railway, adjacent to which are also beds of limestone of excellent quality, which are carried by the railway to furnaces in the coal districts. In this country the mines now worked all afford lead. There was a considerable quantity of copper found in one near Garrigill Gate, in Alston Moor, and in some other mines, but none is obtained at present. Much farther west, in Caldbeck Fells, is a mine called Roughton Gill, in which there are ores of copper and lead in the same veins, in the proportion of $\frac{1}{4}$ copper and $\frac{1}{2}$ lead. The population of this country has been devoted to mining as far back as records can be obtained. As Cumberland was not surveyed by the Conqueror, we have no account of it in "Domesday Book;" but in the Record Office, in the Tower of London, in the Patent Roll of the 20th of Henry III., A. D. 1235, is a copy of a charter, which shows that the mines were then worked, and had been so during the time of the former kings of England.

Working the Mines. — The entrance into the mines is generally by a level driven into the sides of the hills; in former times shafts were frequently sunk from the top, which is now seldom the case. The level is made about 6 feet, sometimes 7 feet high, and from 3 to 4 feet wide; where necessary it is arched with stone, and a railway for the waggons is laid at the bottom. By means of this level, the water is brought out of the mine; carts are drawn in by horses to a certain distance, and the ore put into them; the miners walk into their work, or at least to the places where they ascend or descend. The level is usually driven into the hill as far as possible in the stratum called plate or clay-shale, that stratum being softer and more economically worked than any other. The object in penetrating through the hill by a level is to arrive at a vein of ore, and when the working can be got on the first level it is most advantageous to all parties. In the level of the mine at Stanhope Burn, after proceeding nearly $\frac{1}{2}$ mile, there are several chambers in which the men work, breaking down the lead ore by hammers and picks, drilling holes, charging with gunpowder, and firing it; this extends through the vein of limestone rock as far as 200 fathoms. The tools used by the miners are few and simple, as,

The Jumper, an iron chisel pointed with steel, the usual length of which is 18 inches, and sometimes 2 feet; one miner holds it against the rock, whilst another or a boy strikes the end with a hammer; from time to time the dust has to be taken out of the hole.

The Hammer is used for striking the end of the jumper.

The Pricker. — After the cartridge is put into the hole, the pricker, which is a thin iron rod with the outside end formed into a ring, is driven into it and through the cartridge. When made of iron sparks are produced in siliceous rocks, or even in limestone, both from the hammer and the spade: a copper-pointed pricker obviates this risk.

The Driver. — This is a piece of iron with a broad head, to drive the shale down along the side of the pricker; the head is usually of copper.

The Scraper is for taking out the dust from the hole made by the jumper and hammer.

In breaking down the rock, the lead miners use a pick very like that employed in the coal mines, as well as a great hammer. They first drill a hole in the rock with the jumper and hammer, then insert a cartridge of gunpowder, in the same way as if charging a gun, although the hole may be bored perpendicularly, horizontally, downwards, or sidewards; boys and young persons drill the holes, but are seldom trusted to charge it with the powder. They then drive a pricker through the cartridge, keeping it there for a time, and place what is called plate, or pieces of black shale, at the sides of the pricker, which with the driver they force down as far as it will go, continuing this work until they have filled up the entire hole round the pricker, which is then drawn out by inserting the scraper in the ring at the end, leaving a hole open down to the powder, into which the men thrust a squib to which they apply a match: all except one man retire and get into the level, or some place where the stone directly coming from the explosion cannot hit them, and turn their backs to prevent any piece being reflected into their faces; the man who lights

the match runs away, and after the shot has gone off with much noise, smoke, and dust, the men return and find a chasm made; then with hammers and picks they strike upon every projecting piece of rock, and bring it down. The chamber where they work is filled with smoke by every additional shot fired: if the rock be wet, the patent fuse, being a slow match inside a rope, is found convenient for blasting. When the miners have cut out the ore which is near the level, it is arched over, and they proceed working upwards; the deads or rubbish, or the rock not containing the ore, is let down behind them, as they ascend; different sets of men work above each other, protected by scaffolding. When the ore is removed, it is let down a channel, through an opening called a hopper, into the cart or waggon in the level.

In some mines there is much work in the first level, and it is frequently necessary to ascend and make another; this is effected by drilling and blasting out the rock by gunpowder, and placing scaffolding, by which the miners climb to their work. In this upward work they make a small-landing place, and go from one stage to another, so that they are able to place ladders or pieces of wood from side to side, and afterwards climb up, having halting-places all the way. When arrived at the height thought best to fall in with the veins, they move forward horizontally, or in a line parallel to the first level driven in from the air; it may be necessary to work upwards a second time, and form another flight of ladders, and, after getting to a certain height, again to move forward, and so on several times, until the place of working be 500 or 600 feet above the first level.

The miner who works in such a remote situation walks into the level, as far as the first descent by the ladders, down which he goes, with a load of tools on his back. He then proceeds to the second flight of ladders, and descends to the third, until he comes to the place where he has to perform his work: no air being admitted except from the level by which he has entered, there is nothing to produce a current; the air enters slowly about him, merely by the effect of a difference of temperature, and means are taken to diminish an evil which cannot be removed. Sometimes a body of air is forced by a fall of water from the top surface of the hill, an opening being made for it to descend to the level with great violence, driving a body of air before it, and running out along the bottom of the level from the mine. Machines or fanners, worked by boys, are used, and the air is carried along pipes to places to which it would otherwise very slowly penetrate. Forcing-pumps are sometimes employed to drive it in a similar way, and a supply is obtained by running a second level from the air into the hill, making a communication with the first; in this case the air put in action enters at one level, and goes out by the other. Sometimes a shaft is carried up or let down from the open air into the level, when a current is produced. Few mines have two levels communicating with the open air, or shafts from the outer air down to the levels, the sum required for the purpose being so great that the proprietor prefers to discontinue working rather than submit to the expense; but the men and boys, having no other means of existence, are often allowed to work in the mine with all these inconveniences. The ore dug out of the level, which is entered from the open air, is brought out by a horse and cart, the wheels of which run upon a railway; but that dug in the shafts, above the first levels, is let down holes or channels made for the purpose from one to another, and down to the first or chief level, when it is brought out: when taken from the low levels it is hoisted up by whinseys from one to another, until brought to the first level, where it is carried out to the open day; boys are employed to drive the horses for the whinseys and carts.

The water is raised from great depths by steam-engines or by an hydraulic engine or great water-wheel, which works a pump; that at the surface falls into the buckets of the wheel, and by its gravity causes it to revolve, the water being discharged into the level. The pump brings up the water from a great depth below, and discharges it into the level, where it runs out. This machine is cheaper than the steam-engine, as it requires no fuel, and very little attendance, and works day and night.

In the parish of Stanhope steam power is not used, but water power equal to that of 120 horses: in the mines of Allendale, there are 14 water-wheels, possessing a power equal to 300 horses. It is obvious that the hydraulic machine can be used only on the side of a hill, where there is a stream of water on the surface, which very often occurs in the lead country. The lengths of the levels, driven into the hills, are various: some are half a mile, and some double that distance; there are some much longer, as that nearly 5 miles in length, called the Nent Force Level; it begins near Alston, close by the fall of the Nent, and extends forward to Nent Head. For a long time there was water in this level deep enough to carry boats, by which the ore was brought out, which is now performed by carts, to the foot of a shaft near Nent Head, where it is hoisted up by a whimsey; several shafts, for the purpose of ventilation, are let down into this level.

Of Hushing.—A quantity of ore is obtained by a method called *hushing:* where a great ravine has been formed by the streams on the side of a hill, and water comes down over the stones, clay, and earth, if ore has been discovered, it is a good place for *hushing.* A dam is made at the upper part, with a channel for the water, some of the larger stones

being laid on one side; when the dam is let out, the flood of water, rushing down, tears up the earth and stones, and lays bare new surfaces, when men and boys go into the ravine, and pick up all the ore left by the water. Hushing is chiefly carried on where the ravines disclose new veins, and the water running along tears up the stones containing the metal. Rainy weather, which enables a dam of water quickly to be collected, is favourable to hushing. The work is as easy as washing the ore, and wages much the same, according to the ages of the boys or persons employed. There are many hushing places on the road-side from Weardale to Nent Head, in Alston Moor.

Washing the Lead Ore. — The object of washing the ore after it has been brought from the mine is to separate the lead from the limestone, sandstone, barytes, or other matter with which it is united or mixed up. Some men, and very many boys under 13, and young persons under 18, are employed; as this operation depends on a supply of water, it is necessarily suspended by the frost, and when it has permanently set in, the work is discontinued altogether until the spring; it is also partially liable to be interrupted in dry weather, in places where water is not abundant. It is a great advantage to a mine when it is situated near a river, or a large and copious burn of never-failing water; but frequently it is necessary to take advantage of the smallest streamlets, and artificial means are used to collect water by dams, the outlets of which can be stopped up at nights, or when the people are not employed. In East Allendale, there is a dam which covers 7 acres of land, but in general they are not so large.

Formerly the washing of the ore was a very simple and rude operation. It was placed on a *buddle* or sunk space of ground, with a gentle declivity, so that water coming at one end might slowly flow over the stony bottom to the other, carrying off the loose dirt, clay, or pulverised stone; the solid pieces of ore were broken by a rude instrument called a *bucker*, not yet entirely out of use. This instrument consists of a flat piece of iron, about the size of a man's hand; at the back is a broad ring, through which is thrust a piece of wood for a handle. The boy takes this in his hand, and striking the ore, breaks it into pieces, by which means the water carries off the earthy matter, and leaves the metal behind. The large pieces of lead, thus separated from extraneous matter, are carried away in a state fit for the smelting mill: other pieces are put into sieves. In the distant fells, which will not afford the expense of machinery, and where, also, there may be but a small supply of water, this mode is still in use; a few persons are also employed as auxiliaries to washing establishments, working at buddles along the side of a gill, taking advantage of the streams of water which flow down after a heavy fall of rain.

It is obvious that in this mode of washing many small particles of lead must be carried away, although this is in part obviated by the water falling into pits, and depositing much of the lead. About forty years ago crushing-mills were introduced, and other improvements have since been made, by which the lead is separated from the earthy matter at much less expense, and a greater proportion of lead is obtained: mines are thus rendered more profitable, and some, which, on the old system, would not have yielded a profit, can now be worked to advantage. Preliminary to the operation of the crushing-mill the larger portion of ores are picked out, and sometimes large pieces of pure *Galena*, without any earthy matter, which may be broken with the hammer from the stone, are carried at once to the bingstead, requiring no washing. The ores are at all times placed upon bars of iron, called a grating, and a stream of water flows upon them; the smaller pieces are carried by the water through the bars, and down an inclined plane to a place below; those too large to get through remain upon the grating; some of these are dead pieces of stone containing no metal, which are picked off by boys and thrown aside; the remaining matter of ore and stone goes to the crushing mill. Much depends on the nature of the stratum from which the ore is obtained; some found in a stratum of barytes comes out in dust or small fragments, and may be carried by the waggons, so as at once to be let down, by opening the hole in the bottom of the hopper, which is over the mill; where the pieces are of a larger size, they must previously be broken and grated. The crushing mills require a plentiful supply of water to drive the wheel, as well as to perform the other subordinate operations; they are of various powers, and have the great water-wheel in the middle: on one side are the wheels which break the *bouse* ore, or the ore in its rough state, and on the other side are the *chat mills*, for breaking and bruising the ore which has been crushed or ground into smaller pieces.

The Bouse Ore is discharged from the hopper by a machine called a shoe, or a boy or young person gradually lets it out. In either case it falls between two rollers, deeply fluted, which revolve and work into each other; a body of water falls down between them at the same time. In passing between these fluted rollers the ore is crushed into smaller pieces, which with the rest fall down two inclined planes, one to the right and the other to the left, with a pair of rollers at the extremity of each: these are smooth, and between them the ore passes along with a body of water, and is further ground, and falls into pits below. A certain portion of the ore still escapes, as, when a large piece comes between the rollers,

they are forced to recede sufficiently to let it pass through, when other pieces of stone slip through unbroken, although but for this contrivance the mill might be damaged or choked up. The rollers are, however, immediately brought back to their right position by means of levers, at the end of which are attached large weights, usually stones, for effecting this purpose, and the depression of the lever brings up the roller attached to it to its proper position.

From the pits below the crushing-mill the broken ore is drawn up to the chat mill, on the right side, by means of iron buckets on an endless chain, much in the same way as we see, on a larger scale, the ballast dragged up into the barges from the bottom of the river Thames. Every bucket, on arriving at the top, discharges its load upon a grating, by the bars of which the larger pieces are retained, and are passed again through the crushing mill, or sent to the stamping mill; the smaller pieces are made to pass the three pair of chat rolls, which are exactly on the same plan with the crushing rolls, only on a smaller scale, and adapted to ore of a smaller size. As the crushed ore comes down from the chat mill, a boy stirs it, and the small lead, with the dirt adhering to it, is carried by the stream of water to pits lower down.

The stamping mill is used for breaking the hard refractory pieces of ore, which resist the rollers of the crushing and chat mills. In some establishments the stampers are separate and distinct from the crushing-mill, and in others the same water-wheel turns the rollers of the crushing-mill, and raises the stampers, the broken ore being carried down an inclined plane by a stream of water. When the matrix of an ore is soft and easily broken, the stamping mill may be dispensed with, but for very hard ore it is exceedingly useful.

After the ore has come from the chat mill and the smaller portion has been carried off by water, it is taken up and put into a sieve, to undergo the process called *hutching*. The sieve, made of iron wire, is let into a box which is full of water. From the stalks or chains of the sieve proceed a long lever which rests upon a fulcrum; this is moved up and down by a boy, who places his two hands above his head, and pulls the end of the lever, and in consequence the sieve with the ore upon it is raised up and down with an agitated motion in the water contained in the box, which occasions the very small lead or dust, called *Smiddum*, to fall through the sieve, and sink to the bottom of the box; and of that portion which remains above the sieve, the lead, being the heaviest, works down to the lowest place next the wires of the sieve. Immediately above the lead are the larger pieces of stone, with portions of ore called chats, and above the chats are lighter pieces of stone called cuttings: the cuttings are removed by a limp or broad piece of iron, and given to the cutting cleaners, when it is again put into a sieve and treated as before; the chats are sent back to the mill to be ground again.

It has been already stated that when the ore is laid on the grating, the smaller portions are carried through the bars to a pit below; by a stream of water, part of this matter is sludge or slime, but there is another portion much too large and weighty to be thus carried off: this is taken out of the pits, again put in the sieves, and hutched or jerked up and down in the water on the sieve, by the boy pulling the end of the lever; and when sufficiently hutched, the stony matter is carried off by the limp, and the clean ore lying at the bottom is taken to the bingstead.

The Smiddum is taken from the bottom of the boxes, in which the sieves were agitated, and removed to a running buddle, or space of ground with a stone floor made a little lower than the ground about it, and having a little declivity, over which water runs very gently; upon the upper end of this buddle is put the smiddum, and the water let in upon it. The boys and young persons then stir it with an instrument called a *colrake*, and the water carries away dirt, and the fragments of stone or cuttings, and the lighter ore or smiddum tails are brought to the lower end of the buddle, whilst the weightier ore is left at the upper. The two are thus separated, and the weightier ore is removed to the bingstead.

It is a necessary consequence of the grating and crushing of the ore under the action of water, that a quantity of finely pulverised earthy matter has been collected, and much lead, in the form of minute detached particles, been brought away with it, carried down the stream with the water, and lodged in the pits into which it flows, where all this matter is merely mechanically diffused through it. This mass is more or less stiff, and that portion which is coarse and contains larger grains of lead, is called *sludge*, that consisting of smaller and finer particles *slime*: it is put into trunks and again agitated with water, then laid on the floors of the buddles, and streams of water made to pass over and through it, being stirred and rubbed against the bottom of the buddles whilst the water is flowing, the object being to separate the lead from the clayey matter. The last process is to put the slime into the dolly-tub, where by means of a handle the board is turned round which agitates the slime; the lead then falls to the bottom, and the other matter above is taken away. Many particles of the lead are, however, carried down in the muddy water of the river or burn, and the cattle for many miles below a washing place are not allowed to drink of it.

The apparatus of the Roughton Gill Mine, invented by Mr. John Leathart, of Alston, in Cumberland, and put up in 1840, is found to be of use in facilitating these operations,

and also for washing poorer lead. Its principle is that of separating the different kinds of ore, by passing them through plates full of holes of various sizes.

The ore when brought from the mine is grated, that is to say, those portions are thrown aside which are considered not to contain lead, and the large pieces of ore are broken up with hammers, and made to pass through the crushing mill; after which it comes on to a separator, or broad plate with holes in it, of ½ inch in diameter; that which remains on the plate and cannot get through the ½ inch holes is sent back to the crushing mill to be re-ground; that which passes through the holes is carried by the water down to plate No. 2., the holes of which are ¼ inch in diameter; what remains on this plate, or is too large to pass through the holes, is taken to the sieve or the shaking apparatus, where the small portions called *smiddum* go through, the cuttings are thrown out, and the small ore at the bottom is taken to the bingstead.

The chats which come out of the sieves or shaking apparatus are ground, and come to a plate No. 1., and the rough, which cannot pass through the holes, is taken off and sent back to the chat mill again; what falls through is carried by the water to the surface of plate No. 2., which is laid in an inclined position; the smiddum passes over and the sludge goes through; the former is then put into the shaking apparatus, to be separated in the same manner as in other washing-places; the cuttings are taken out, and the lead is removed to the bingstead.

The Sludge Separator is carried by water to the surface of plate No. 1.; the holes are ⅛ of an inch in diameter; the rough sludge is carried off by the water and the small falls through the holes, and runs into trunks or buddles, the rough passing through another buddle.

The slime is made to pass over plate No. 1., when the lead drops through, and is carried to the inclined plate No. 2.; the rough passes over, and the small, which falls through, is afterwards treated as we have already described. The lead which remains at the upper end of the buddle or trunk is put into the dolly-tub, and the matter at the lower end is put into another separator of the same kind.

The cuttings which come from the sieves are carried by water to a small grate; the stones remain above the grate, and are then removed and thrown away; what falls through goes on to an inclined plate with holes in it; the rough is put back again to undergo the same operation.

The Smelting Mills are buildings for reducing the *crude ore* to lead, and separating the silver contained in it.

The operations consist of *roasting the ore; smelting the roasted ore at the smelting hearth; roasting and smelting the ore* in one operation at the smelting furnace; *refining the metal*, by exposing the lead to the flames of a reverberatory furnace, by which it is converted into *litharge*, and the silver left behind; separating the silver and lead, removing the greater part of the latter, and sending to the refining furnace the portion containing the silver.

Roasting the ore in a reverberatory furnace is precisely the same in principle as that adopted for puddling iron, and at the balling furnace used for heating the iron before passing through the rolls. A *bing* of lead ore is introduced at one time, and heated to ignition, but not to melting; too little or too much heat is considered equally bad. The flame of the fire strikes against the ore, and when it shows a yellow flame, it is stirred with a paddle or iron rod with a broad end. The stirring must be repeated five, six, or seven times in a heat. This depends on the nature of the ore, varying from one hour and a half to three hours. A barrow, containing a bing of ore, is wheeled from the bingstead, and placed over the furnace ready to be let in when required. When the ore is sufficiently roasted it is raked forward by degrees and let fall into a cistern, and the heated water which flies up is prevented by an iron plate from reaching the workmen. A reverberatory furnace is one in which the flame and heat are carried forward by the draught of air, and dashed against the bodies to be smelted.

When one heat is over, another bing is let into the furnace, and the same work is repeated. Two men are engaged eight hours at a time; they are succeeded by two others, who work eight hours; the first set return and work another eight hours: in this manner they proceed day and night for four days in the week, it being considered a great saving of fuel not to let the furnace cool.

Roasting the ore drives off the sulphur from the galena or sulphuret of lead, of which it is composed as well as the antimony and other matter more volatile than the lead. The small dust ore is made to adhere together, whereas, if it were to be put into the smelting hearth, and exposed to the blast, a great portion would be lost.

The roasted ore is let fall into water to prevent its forming unwieldy lumps, as it would do if left to cool in a heap. The ore is then taken from the water and carried to the smelting-house.

Of the Smelting Hearth. — Its usual dimensions are 22 inches long and 22 broad, and about the same in depth; but these vary at different places. It is made of cast-iron, and charged with half-melted matter of former operations, with peat and coal, and the roasted

ore. A large bellows throws its blast into the hearth, whilst two men working together stir the melted lead, and gradually add more ore. There is a small channel in the hearth in which the melted lead flows into a pot at the side of the brickwork in which the hearth is fixed, from which the men lift up large ladles of the metal, and pour it into moulds. At most smelting-mills the smelters are divided into three sets of two men each, who come in turns, ten hours each set at a time, so that each works ten hours and rests twenty. Lime is sprinkled on the edge of the hearth when melted slag is running off, which has the effect of uniting with the slag, and converting it into a solid.

Smelting-furnace is of the same description as the roasting-furnace, already described; the roasting and smelting are both done in one heat, which occupies about five hours, coal being mixed with the ore to smelt it. A bing of ore is roasted and smelted at one shift; the smelting furnace, requiring more fuel than the smelting hearth, is not used where coals cannot be readily procured. The process of roasting being effected, the doors of the furnace are shut, and the heat is then increased sufficiently to melt the ore.

Of the horizontal Chimneys. — It is important that the chimneys of smelting mills should carry off the effluvia, so highly injurious to the workmen. About twenty years ago horizontal chimneys were first used, some of which were more than 100 yards in length. The chimney at the Derwent Company's mines is a mile from the smelting mills, and proceeds under ground the whole of the way up the side of the hill to the foot of a lofty turret, carrying off the destructive smoke, but which, falling upon the ground, renders the grass poisonous to the horses and cows partaking of it.

To prevent the land from being injured by the smelting-hearths an arched tunnel, a mile long, is usually conducted to a chimney shaft, which at the end of the year is cleaned, and the matter smelted, by which means a sufficient quantity of lead is obtained to remunerate the expense of making the tunnel.

The chimney in Allendale is 3 miles in length, from which many thousand pounds worth of lead are obtained, the farthest smoke being the richest in lead. This tunnel or chimney is 3 feet wide and 6 feet high, so that it may be effectually cleansed.

The smelting mills are generally placed in a low situation, on account of the water necessary to turn the wheels which give motion to the blasts. It is obvious that a tunnel carried from such a situation up the side of a hill to a great height will have a strong draught of air, and consequently draw off the smoke and effluvia from the metal, and the noxious matter so ruinous to the health of the workmen.

Refining the Lead and Silver. — The process of refining the lead and silver depends on the principle, that lead exposed to heat readily imbibes oxygen from the atmosphere, and becomes oxide of lead, whilst the silver remains unaltered. It is carried on in a reverberatory furnace, which allows the flames from the fuel to strike against the lead and silver; the lead is converted into litharge, and the silver, formed into a plate, remains below. Before the metal is put into the furnace a test is made from the ashes of bones or those of ferns or brakes (Pteris aquilina). This plant, when burnt, yields a vegetable alkali, or potash, which constitutes its value as a test. A mixture is made of the bone and fern ashes, beat up with water, and afterwards moulded into an oval form, and placed within an iron frame in the furnace, with the pig of lead upon it: some of the litharge is absorbed by this mixture, and its quality tested. The flames change the lead into a semi-vitrified oxide or litharge, the melted lead abstracting oxygen from the air. On one side is an opening, and at the other the blast of a large bellows is introduced, which blows the litharge from the surface, and occasions it to fall through an opening into an iron vessel placed to receive it, which, when nearly full, is removed, and another put in its place. The test absorbs in two or three days such litharge as is below the silver, with a part of the silver.

Of the Separation of Lead and Silver. — The present mode of separating these two metals was discovered by Hugh Lee Pattinson, of Alston, an agent employed by the trustees of Greenwich Hospital to test the lead paid to them as their royalty, to ascertain the quantity of silver it contained, and to determine its value. In the course of conducting his operations he observed that part of the lead crystallised before the rest, which induced him to attempt to discover the cause; and on analysis he found that the portion which continued longest liquid contained a larger proportion of silver.

The operation, as now practised, may be thus described. Three cast-iron pots are set in brick along the middle of the chamber; when the lead is melted in pot No. 1., it is stirred with an iron rod, and every now and then the lead which adheres to the rod is removed with a great hammer. On the other side a man with another rod, at the end of which is a ladle full of holes, dips it into the pot of melted lead No. 1., and, pressing it on the edge of the pot as a fulcrum, raises up the ladle nearly full of lead, curled, crisping, and frosted, which runs out in a liquid metal from the holes in his ladle. This is held above the surface, and shaken till no more metal will run out, and then the lead is emptied into pot No. 2. This operation is continued until there be very little liquid metal left in pot No. 1., if there be a breeze of wind through the room, the lead cools faster, and the work goes on more rapidly. The metal in pot No. 1. is then brought into moulds and cast into pigs,

and that put into pot No. 2. is melted, and is treated in the same way as the lead in pot No. 1. The lead taken away is then put into pot No. 3., and melted and treated in the same manner, when it is found to contain so little silver that it will not defray the expense of melting it a fourth time.

In some mines the lead is richer, as at Greenside, where there are five pots in the separating room; the lead of this mine contains from 12 to 14 ounces of silver to the ton, and there is sufficient silver, after it has been melted and separated the third and fourth time, to cover the expense, and yield a profit in melting it again.

Of the reducing Furnace. — Under the new system, before the remaining lead and silver is subjected to refining, comparatively little litharge is made, although there is more than can be sold at a remunerating price, either to the glass-makers or the colour-makers; much, therefore, is reduced to metal in the reverberatory furnace, at the bottom of which is placed a layer of coals, and the litharge, mixed with small coal, is put in and exposed to the flames. During the combustion the small coal abstracts the oxygen from the litharge, and pure lead is the result, which is cast into pigs of 12 stones each, and is in a malleable state.

Reducing the Slag. — The slag is put into a furnace, mixed with coke and heated by fuel beneath: the oxygen of the slag enters into combination with the fuel, and the lead is separated and cast into pigs. This is less valuable than the other, and is easily broken.

Cast Lead is manufactured by melting the pig-lead in a large iron vessel, and then ladling it out on a table 18 or 20 feet in length, which has been previously covered with fine pressed and beaten sand, brought to a level and smooth surface by passing a strike over it. The table has a rising edge all around it, on the top of which is a movable strike, which determines the thickness to be given to the sheet; this strike, when the metal is in a liquid state, sweeping before it the superabundant lead. When a very thin sheet is required to be cast, a linen cloth is stretched over another of wool, on which is poured the lead, care being taken that the heat is not sufficient to set fire to the paper, and it is requisite, as the lead cools rapidly, to be very adroit in passing the strike over it.

Milled Lead is first cast in sheets, and then passed under rollers, placed at such a distance apart as is required for its thickness, the space between each pair of rollers it passes through diminishing gradually: the weight in pounds of a superficial foot is

	lbs.
When of a sixteenth of an inch in thickness	$3\frac{3}{4}$
a twelfth	5
a tenth	6
an eighth	$7\frac{1}{2}$
a sixth	10
a fifth	12
a quarter	$14\frac{3}{4}$
a third	$19\frac{3}{4}$
a half	$29\frac{1}{2}$

The weight of a cubic foot of lead is $709\frac{1}{2}$ pounds, and Smeaton found that a bar 12 inches long, 1 inch square, and weighing 4·94 pounds, was expanded by 1 degree of heat $\frac{1}{62500}$. Lead melts at 612 degrees, and will bear a weight of 1500 pounds on each square inch, without altering its form materially. Compared with cast-iron its strength is ·096; its extensibility 2·5 times, and its stiffness ·0385 times.

Casting of Leaden Pipes is comparatively a recent invention; for those used in water-works were commonly made of sheet lead wrapped round a wooden or iron core, and where

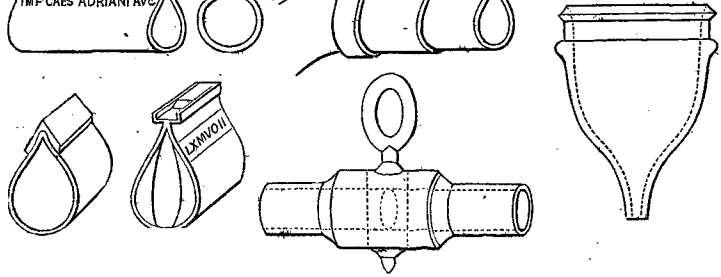


Fig 584. PIPES FOUND AT LYONS.

the edges met, they were soldered together: pipes so made are very liable to burst, from the soldered joint giving way. Some of the pipes found at Lyons, near the Roman aqueducts, were evidently made in this manner, and perfectly agree in form with those Vitruvius describes.

Pipes are sometimes cast in an iron mould made in two halves, and afterwards united to form a hollow cylinder, into which a core or iron rod, the size of the intended bore, is introduced; the two halves of the iron mould are secured in their position by screws or wedges, which make the core that occupies the centre fit in such a manner that there is an equal distance all round to receive the melted metal, which enters it by means of a spout, care being taken to allow the air to escape. The mould is fixed to a long bench, and a rack moved by toothed wheels and pinions is fitted to one end of it, in a line with the centre of the mould, which by means of a hook connected with an eye at the end of the core enables it to be drawn out when the pipe is cast: when this is done, the iron halves which form the mould are separated, and the pipe is moved onwards, an inch or two of its end alone occupying the mould; the halves are then again secured together with the core between them, and its end entered again, an inch or more into the first piece of pipe; the mould is filled with melted lead, the heat of which unites it with the end of the first piece, so as to double its length, and the core being again drawn out is ready to be used for another piece. Any length of pipe may be thus cast, but the metal is very subject to air bubbles, and the joinings are far from sound. The usual method now is, to cast the lead in an iron mould upon a cylindrical rod of the size of the intended bore, leaving around the core a space three or four times the thickness of the intended pipe; after they are cast in short lengths, they are drawn through holes of steel plates, and reduced to the thickness required. Another process is to reduce the pipe by passing it through two rollers of a flatting mill, in each of which semicircular grooves are formed all round, so that the two

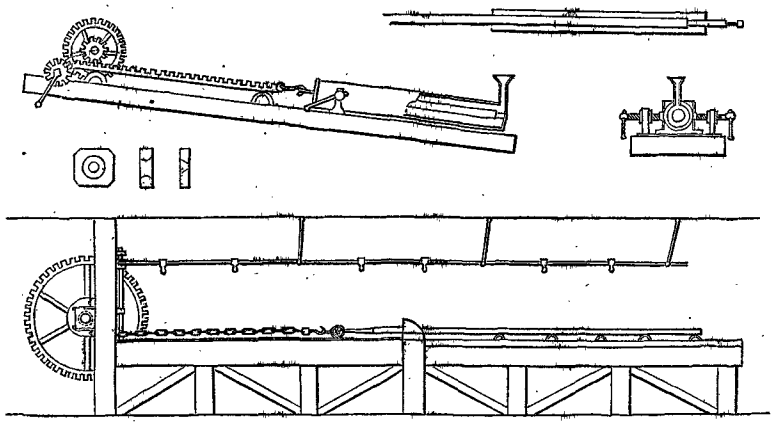


Fig. 585. MACHINE FOR FORMING LEAD PIPES.

rollers when united have circular cavities between them, which gradually diminish in diameter from one end of the rollers to the other. The pipe after passing through the largest cavity, then the others to the smallest, is diminished in its thickness or substance; and by this process also hardened and rendered stronger.

The section shows the two half moulds screwed up in their place, with the core or treblet in its position; and great care is required that the interior surface of the former is truly cylindrical, and that the latter is accurately turned in a lathe, so that an equal space is left around or between the two, or the metal will be cast unequal in thickness. The inclined plane on which the process is conducted is necessary, in order that when the metal is poured in at the cup at the lower extremity, the air may pass out at a hole or vent left at the upper end, where the hook is connected with the rack. The core has a neck or smaller part at the end, which prevents its being drawn through the pipe; and by means of the rack and pinion, the pipe is drawn to its required length.

The other machine has a strong timber framework with a cog-wheel moved by a steam-engine or water-wheel, and which can be put in motion by the handles or levers shown above the stage. The drum of the cog-wheel has a pair of spiral grooves formed on its circumference, for the reception of two chains, the ends of which are hooked to a little carriage on wheels, and which has at the back a double claw to engage in the notches made at the end of the core or treblet. In the middle of the bed is a cast-iron frame,

securely fixed on a short cross-bearer; in this is a notch in the upright side nearest the roller, which allows the treblet and pipe to pass through, and also forms a hold for the steel plate through which the pipe is drawn: these steel plates or whirtles vary according to the sizes of the pipes, and are movable at pleasure; they are made rounding on one side, to allow a more ready exit and entry of the pipe, and diminish gradually, from the size of the rough cast pipe to that required. When the lead pipe is fitted to the treblet, it is laid upon the rollers on the bench, and the end of the treblet being put through the largest set of whirtles, it is hooked on to the carriage, and the whirtle lodged against the cheeks of the frame. The drum is then put into gear by means of the handles and levers, and, winding up the double chains, the pipe is drawn through the whirtle, and diminished in size as it is lengthened. After the pipe is drawn entirely through, the roller is cast off by shifting the levers; the treblet is then unhooked from the carriage, and pushed back into its former position, and a smaller whirtle being put on, the pipe is drawn through as before; the operation is repeated through smaller whirtles, until the pipe has acquired its proper thickness: this is sometimes performed through a dozen, when it is made perfectly even and smooth; the elevation and two sections of the whirtles are shown above the machine. By this means lead pipes are drawn out in lengths of from 10 to 12 feet; after which, by a process termed burning, they are united together; this is performed by passing through one pipe an iron core, which enters a few inches into the other, and a small iron mould put together in two halves over the ends of the two pipes, which are brought close together. Melted lead is then poured into the mould, which runs out by a hole in the bottom; when the stream of lead has run a sufficient time to fuse the ends of both pipes, a slider is made to pass over the hole, and the mould being left full is suffered to cool, when the pipe is removed.

Zinc or Spelter has a crystalline texture, is brittle at ordinary temperatures, and of a bluish white colour: at 300°, it is both malleable and ductile, and at a white heat is converted into vapour. When pure zinc is exposed to air and moisture, it acquires a dull colour from partial oxidisement; and great electric action takes place when it is in contact with copper, and the zinc decays in consequence. Its specific gravity is 7, and it has a great attraction for oxygen; the weight of a cubic foot is 439¼ pounds.

Oxide of Zinc is obtained by intensely heating the metal exposed to air; it takes fire at a red heat, if the air is freely admitted, burning with a very bright flame.

Zinc	1	32	80
Oxygen	1	8	20
	1	40	100

Sulphuret of Zinc (*Blende*) is found native, and is a brittle soft metal of a brown and black colour; its primitive form is a rhomboidal dodecahedron, and it is a most abundant mineral. The pure metal is obtained from it by roasting the ore, and afterwards distilling it when mixed with charcoal.

Zinc	1	32	66·5
Sulphur	1	16	33·5
	1	48	100·0

Carbonate of Zinc (*Calamine*): when found crystallised, its primitive form is an obtuse rhomboid.

Oxide of zinc	1	40	64·5
Carbonic acid	1	22	35·5
	1	62	100·0

Zinc is obtained from the sulphuret and carbonate; the ore when broken is submitted to a dull red heat in a reverberatory furnace, when the carbonic acid is driven off from the calamine, and the sulphur from the blende: it is then mixed with ⅛ of its weight of powdered charcoal, being first ground and thoroughly washed, and distilled by the application of a red heat; the metal being put into earthen pots with iron tubes cemented into the lower parts, dipping into water, where it is collected, and afterwards cast into cakes. A bar of zinc 12 inches long, and 1 inch square, weighing 3·05 pounds, expands in length at one degree of heat $\frac{1}{81200}$, and melts at 648°; it will bear, without permanent alteration, a pressure on a square inch of 5700 pounds.

Zinc is used for the preservation of iron, by electro deposition. The iron is first rendered perfectly clean and free from oxide, by placing it in a bath of heated sulphuric acid and water; then in a cold solution of sulphate of zinc. The positive pole of a galvanic battery is attached to a zinc plate, and the negative to the iron to be covered; the pure metal is deposited, and the zinc and iron are amalgamated. Wooden troughs are em-

ployed for the process, and iron plates so covered are extensively used for roofing, and do not after many months exhibit any signs of decay. The iron being coated with zinc in a cold solution does not in any way change its condition; but when the zincing of iron is performed, by steeping it in a bath of melted zinc, a combination takes place between the two metals, and a brittle alloy is the consequence, the iron losing all its tenacity.

Tin is usually prepared from the native oxide, its oxygen being removed by charcoal: the purer kinds are called grain tin, and the others block tin. The common ores are known under the name of mine tin, and furnish a less pure metal than the stream tin. Tin has a silvery white colour; its specific gravity is 7·3, and air and moisture have little effect upon it: it melts at 442°, and is converted into a white oxide by exposure to heat and air.

The specific gravity of the native peroxide of tin is 7·, and its primitive crystal an obtuse octohedron.

Protoxide of Tin: specific gravity 6·6: —

Tin	1	58	87·8
Oxygen	1	8	12·2
	1	66	100·0

Bisulphuret of Tin, (*Aurum musivum*, *Mosaic Gold*,) is a mixture formed by heating peroxide of tin, which contains two of oxygen and one of tin, with its weight of sulphur. Bisulphuret of tin is also formed by decomposing perchloride of tin by sulphuretted hydrogen; it is quite insoluble in the acids, except nitro-muriatic; it forms the bronze powder used by paper-stainers.

Tin	1	58	64·4
Sulphur	2	32	35·6
	1	90	100·0

The weight of a cubic foot of cast tin is 455·7 pounds, and the weight of a bar 12 inches long and an inch square is 3·165 pounds; it expands, according to Smeaton, at one degree of heat $\frac{1}{7250}$, and melts at 442°. It will bear on a square inch 2880 pounds without any permanent alteration, and an extension of length of $\frac{1}{1800}$. Compared with cast-iron, its strength is 0·182 times, its extensibility 0·75 times, and its stiffness 0·25 times, cast-iron being considered as unity.

Copper is found native, and of its ores the most remarkable are the oxide, sulphuret, sulphate, carbonate, chloride, arseniate, and phosphate. It has a red and brilliant colour, is malleable and ductile, melts at a dull white heat, or at 2548°, and in oxygen gas burns with a green light; when long exposed to moist air a green crust of the carbonate is formed upon its surface. The weight of a bar 12 inches long and 1 inch square is 3·81 pounds, and its length is increased by one degree of heat $\frac{1}{10390}$. Its specific gravity is 8·8, and the cohesive force of a square inch is 33,000 pounds when hammered. Copper is principally prepared from the native sulphuret of copper and iron, which is heated with a flux of charcoal and siliceous matter; the sulphur is first expelled, and the metals oxidated; the oxidated iron forms a slag with the flux, and the charcoal reduces the oxide of copper. When the ore is broken, it is heated in another reverberatory furnace, where it is fused, and the remainder of the slag removed from it, when it is cast into pigs, which are again broken up and melted with a portion of charcoal. The metal is rendered malleable by constantly stirring it when in the furnace with a pole of green wood, and it is afterwards cast into cakes 18 inches by 12, the weight of a cubic foot of which is 549 pounds.

Oxide of Copper is black, insoluble in water, but with acids forms coloured salts.

Copper	1	32	80
Oxygen	1	8	20
	1	40	100

Sulphate of Copper (*Blue Vitriol*) is formed by dissolving peroxide of copper in diluted sulphuric acid; its crystals are of a fine blue colour, and in rhomboidal prisms. The common blue vitriol is obtained by exposing roasted sulphuret of copper to air and moisture, but it is often impure, from the iron and zinc it contains. When animal substances are imbued with it and dried, they remain as it were preserved, and it has been employed in a state of solution to immerse timber for the purpose of preventing the dry rot. The crystallised sulphate of copper contains

Oxide of copper	1	40	32
Sulphuric acid	1	40	32
Water	5	45	36
	1	125	100

Sulphuret of Copper is an artificial compound.

Copper	1	32	50
Sulphur	1	16	50
	1	48	100

Carbonate of Copper (*Malachite*) is found native, but never regularly crystallised; it is of a fine green colour, but sometimes of a beautiful blue.

Oxide of copper	2	80	78·43
Carbonic acid	1	22	21·57
	1	102	100·00

ALLOYS OF COPPER. — *Ormolu* is an alloy of copper and zinc in equal quantities, melted at the lowest temperature at which copper will fuse; they are then stirred together, and when thoroughly mixed, a further quantity of zinc is added in small quantities, until the alloy has attained in the melting pot the desired colour. It should be observed that the zinc will fly off in vapour if the temperature is too high, and the residue will become spelter, or hard solder only; but when the operation is properly managed the alloy will acquire first a brassy yellow, then, by adding a little more zinc, a purple or violet hue, and afterwards become perfectly white, which is the proper hue for the compound in a fused state.

Sterling or Standard Gold consists of 11 of gold and 1 of copper — specific gravity 17·157.

Brass is an alloy of copper and zinc, usually in the proportions of from 12 to 18 per cent. of zinc; its specific gravity varies from 7·8 to 8·4. It may be also made by mixing 50 parts of oxide of copper, 100 of calamine, 400 of black flux, and 30 of charcoal powder; these melted in a crucible till the blue flame is no longer seen, a button of brass of a golden colour is found at the bottom, weighing about one-sixth more than the pure copper obtained from the same quantity of oxide.

Pinchbeck, or Dutch Gold, contains more copper than exists in brass; a little tin is sometimes added.

Speculum Metal is an alloy of copper, tin, and arsenic.

Bell Metal and Bronze: the former consists of 3 parts of copper and 1 of tin, the latter of from 8 to 12 of tin with 100 of copper; when a shrill sound is required zinc in a small proportion is added, and sometimes lead. Bronze requires its texture to be softened when heated, and then suddenly cooled.

Tinned Copper.—Vessels intended to be tinned have their surface cleaned and washed with sal-ammoniac; a bit of tin then rubbed over it unites and covers the copper.

Gun Metal: copper 663, tin 336; another variety, copper 764, tin 236.

Bronze for Statues usually contains 0·20 parts of tin. In an ancient Egyptian poniard was found 85 copper, 14 tin, and 1 iron: in a mirror 62 copper, 32 tin, 6 lead.

German Metal: copper 534, nickel 175, zinc 291; it resembles silver of 18 carats; it is employed in the manufacture of all ornamental works where silver is used: 90 parts of copper, 5 of zinc, and 5 of antimony, is the best alloy to make plummer's blocks for the iron or steel gudgeons of machinery to run in.

The Copper and Tin Mines in Devonshire and Cornwall may be considered to commence at Dartmoor and terminate at the Land's End. The surface of the country is gently undulating, the loftiest hills rarely exceeding 1000 feet above the level of the sea, and the planes at their bases are in general from 100 to 200 feet above high-water. The highest peaks are granite, and the lower hills and the plains consist of various slates. The granite may be said to occupy Dartmoor, the neighbourhood of Rough Tor and Brownwilly, the Hengsbarrow district, the Cairn Bren range, which is separated from that of Wendron by a narrow slip of slate near Pendarvis, and the western tract, which extends from St. Ive's to the Land's End. Granite is also found at Kithill, Brenge, and St. Michael's Mount, and in a few other localities. All the other parts of Cornwall (except the Lizard district, which is of serpentine,) may be considered to consist of slate of various kinds.

The granite, in general cross-grained and of porphyritic structure, contains felspar, quartz, and mica; but in some places the mica is replaced by talc; the rock is then called China-stone, the felspathic portions of which, when decomposed, are washed out and prepared as porcelain earth for the manufacture of earthenware. In some of the granite schorl abounds. In the year 1838, 28,000 tons of this porcelain clay and China-stone were exported from Cornwall to the Potteries.

The slates are in general felspathic, and near the granite their structure is often compact, whilst at greater distances they are lamellar and schistose in their structure, and still farther off they become fissile, and make excellent roofing slates. The laminæ of the slates usually dip from the granite, round the flanks of which they are symmetrically arranged,

which has occasioned it to be observed, that the granite peaks rise like islands in an ocean of slate. The range or bearing of the masses of granite is about north-east and south-west, and the mines occur on both sides of it. Both the granitic tracts and the slates in their vicinity are intersected by veins or dykes of a porphyritic felspar rock (provincially called Elvan). These veins have been traced for miles, passing uninterruptedly through both granite and slate; their usual direction is about 20° south of west, and they are generally several fathoms in width: where they fall in contact with the veins they appear as if they had been portions of the strata.

The schistose varieties of the slate formation, considerably above the granite, contain beds of limestone, which coincide in position with the slaty laminæ, but are more generally irregular and unconformable. The metalliferous veins or lodes have an average direction of 4 degrees south of true west, but the general bearings are not the same in other parts of Cornwall: those of St. Just, for example, run about 35° north of west; in the same district, and even in the same mine, (as at Dolcoath, East Wheel Crofty, &c.), there are often two series of lodes, one bearing nearly east and west, whilst the others, called counter-lodes, are nearly south-east and north-west.

The dip or inclination of the lodes is about 60° or 70° from the horizon, and four out of six may be said to incline towards the nearest mass of granite; the lodes near Dartmoor are for the most part flatter than those in the west of Cornwall. Taken on the whole they appear tolerably straight in direction and in inclination, but when examined in detail, it will be found that they exhibit almost continual curvatures or irregularities; still, however, these flexures seem projected on certain lines, which have considerable constancy.

The width of the lodes on the average is about 3½ feet, but they vary from a mere line to 40 or 50 feet; each lode seems to have a natural or casual breadth of its own. The composition of the lodes is as variable as the nature of the rocks through which they pass; the greater number is composed of earthy matter, of the nature of the contiguous rock, mixed with large quantities of quartz. These ingredients are sometimes in separate veins, but for the most part are mixed without regularity or order; through them the metallic ores are dispersed, sometimes thickly, or in irregular lumps connected with each other by small veins of ore; in other cases the ore is very sparingly sprinkled through the earthy matter of the vein, and in some rare instances forms the larger part of its contents. The masses of ore in the lodes usually dip from the granite, and the deepest parts of the mines are consequently farthest from where that rock appears at the surface.

There is a second series of veins which run nearly at right angles to the lodes, called *cross-courses* when they are composed of quartz, and *flucans* when of clay. The general direction of the former is somewhere about south-east and north-west: their dimensions are variable, being perhaps on an average 2 feet; their dip fluctuates, but as a general rule, it is greater from the horizon than that of the lodes. It has been already mentioned that quartz and clay form the larger part of their ingredients: this clay is invariably of the same character as the contiguous rock.

Tin and copper ores are occasionally found in small quantities in the *cross veins*, and in two or three instances silver and its ores have occurred to some amount. The chief metallic produce of this class of veins is lead ore, but they seldom yield it in the neighbourhood of lodes which are productive of other metals; it being a general law in Cornwall, that two series of veins, at right angles to each other, are seldom found productive in the same district.

Both the *lodes* and *cross veins* ramify and divide, and whilst the one which is rich will sometimes within a short distance dwindle away, that which is small will often enlarge and become productive.

As these two varieties of veins run at right angles to each other, they of course frequently meet and intersect. There are a few cases of the lodes traversing the *cross veins*, but in the larger number of instances the cross veins cut through the lodes, and occasionally simply intersect them, but generally a displacement attends their contact, the separated portions of the lodes not occurring exactly opposite to each other on both sides of the cross vein. These displacements are called *heaves*, and although they are usually for a few feet or fathoms only, yet some cases are on record where the discordances are as much as 20, 30, or 40 fathoms, and in one instance 72 fathoms. It is not easy to lay down a rule for finding again the second portion, but it is perhaps rather more frequent to discover it on the side of the obtuse angle formed at the intersection than on the acute. It is obvious that on whatever portion of the *lode* we approach the cross veins, the other will be found towards the same hand; the separated portions are more commonly found towards the right hand than the left. These *heaves* are the most intricate and baffling phenomena with which the Cornish miners have to contend.

There is a third series of veins bearing parallel to the lodes, which are generally of small size, and consist of clay, called *slides*. These are confined to the slate districts, and seldom metalliferous: they intersect the lodes on the lines of their inclinations, and cut off the lower

from the upper parts, producing similar displacements vertically as those which the cross veins occasion horizontally.

Taking the granite and slate with the lodes which traverse them, it appears that the largest part of the *tin ore* obtained in the west of England is from lodes in the granite, and that of copper ore from veins in the slate, though the richest masses of tin ore yet discovered have been in slate, whilst the bunches of copper ore found in the granite have in a few instances been as large as any which have occurred in slate.

It is a prevailing and apparently well-founded opinion among practical miners, that the lodes are most productive near the junction of the granite and slate rocks; accordingly the mines, instead of being irregularly distributed over the face of the country, are clustered together near the lines of these junctions, and the heaps of rubbish separated from the ores may be traced in such situations for considerable distances on the lines of the chief lodes, rising in some cases amidst rich fields, and destroying the vegetation like streams of lava from a volcano.

The St. Just mines form one group near the Land's End, those near St. Ive's another, at the opposite ends of the same granite mass; those of Breage a third, subordinate to the granite of Godolphin and Tregoning hills. The Crowan and Gwinear mines stand at the western extremity of the Cairn Brea and Wendron granite, whilst those of Camborne and Redruth skirt it on the north, and those of Wendron on the south, and the Gwennap district occupies its eastern flank. In like manner many of the St. Agnes mines are located near a small patch of granite at Cligger Point; those of St. Austell are grouped on the skirts of the Hengsborough granite; whilst the mines near Callington and Tavistock are contiguous to the Kithill and Dartmoor ranges.

TIN ORE is also found in deposits generally considered diluvial, mixed with the debris of different rocks, covered with an alluvial bed. Repeated washing by means of running water being the chief process to which such tin is subjected, the designation of *stream-work* is commonly applied to this method of obtaining the ore. In a solitary instance at Carnon, this stratum of tin stuff is removed by subterraneous excavation, the alluvial bank or overburthen being too thick to be taken off, and it is subject likewise to be covered by the sea at high water.

Mines of iron and manganese, giving employment to a considerable number of persons, fall also within the district above described; among them those near Lostwithiel are the most important. The ore lies in a vein, nearly vertical, and of an average thickness of 10 feet. The greater part of this mine is worked open to the surface, and the access to the underground part is by levels: the greatest depth does not exceed 50 fathoms. The manganese mines, which are chiefly situated on the borders of the two counties, are likewise very superficial, the workings being seldom carried more than from 20 to 30 fathoms from the surface. Antimony has also been raised to some extent, but the foreign ores of this metal have of late years almost monopolised the market, and very few persons are now employed in obtaining it. The mines of tin, copper, and lead, with the latter of which metals silver is generally united, are those which present the characteristic features of the mining of the west of England.

When it is known or thought probable that a lode which will repay the cost of working exists in a particular locality, the usual course of proceeding is to sink a shaft vertically to a certain depth, which shall intersect the lode. If this cannot be done, a gallery or level is driven or excavated at right angles to the shaft, in the assumed direction of the lode, and continued till it is reached: in either case, when reached, a level is driven horizontally along its course, the miner working upwards and removing the rock from above. It must depend on the thickness of the vein and its inclination, whether it is necessary to excavate any of the adjoining rock, and to what extent. Meantime the shaft being sunk still deeper, another gallery or level is carried along the vein or lode, usually about 10 fathoms below the former, and the metalliferous stone intervening between the two levels is subsequently removed. This process is repeated again and again, and as the workings become more extensive in length, additional shafts become necessary. Horse and water power are made use of for effecting the earlier operations, but the steam-engine is employed in most of these mines; and as they increase in depth and extent, very powerful machinery is needed to raise the excavated rock and the water. Shorter shafts, called *winzes*, are formed at intervals between the levels, for the purpose of ventilation. In proportion to the dip or inclination of the vein, there must be an advance in a horizontal direction, as the depth of the workings increases, which renders a communication necessary from the lower levels to the surface, in a more direct manner than can be furnished by the shafts. At a very early stage of this process, a separation is established between the shafts by which the men pass to and from their work, and those in which machinery is employed. This separation is effected by a boarded division in a single shaft, or by devoting two distinct shafts to these purposes; excepting the occasional raising of men and boys in buckets through short distances, ladders are the universal means of ascent and descent in these mines. Many of the shorter shafts, or *winzes*, are provided with ladders, so that the course taken

by the miner is commonly not one of continuous descent and ascent, but varied by his traversing at different intervals a considerable length of horizontal galleries.

Mr. De la Beche in his geological report has estimated the value of the mineral exported produce of Cornwall and Devon in 1837, as follows:—

Copper	952,855
Tin	415,518
Manganese	40,000
Lead	3,000
China-stone and clay	43,000
Granite	24,500
	£ 1,478,873

The smallest height of the levels in Carnon mine from which a horizontal bed of tin stuff is removed is 5 feet, and the thickness of the vein of ore 3 feet; and the ore is about 13 fathoms from the surface of the ground.

St. Ive's Consols well illustrate the character of the greater part of the tin mines. The smallest height of the levels is seldom less than 6 feet; the thickness of the bed or vein of ore is from a few inches to 10 feet, and sometimes more than double that in width. The lodes in this district enter the rock at the surface, at an angle of 50°, 60°, or 70°, from the horizon, and sometimes almost vertically, and if productive, from any given level to another, are regularly cut away, after first supporting the sides and roof of the level with timber frame-work fitted to the angle of the lode, which in few cases proves otherwise than completely safe and secure. The workings below the level or surface of the ground vary from 30 to 147 fathoms, and 20 fathoms from the *adit*.

In the Charlestown tin mines the smallest height of the levels is 7 feet, and the thickness of the bed or vein of ore is from 3 to 10 feet. In the copper mines in the central district, in the United Mines for instance, the levels in the ancient workings do not exceed 5 feet high and 2 feet wide; but those made recently are about 7 feet high and 4 feet wide. The veins are nearly perpendicular, and vary from 1 inch to 9 feet wide: the ores are got from between 40 to 220 fathoms from the surface. In the Consolidated Mines of this district, the deepest, the smallest height of the level is 6 feet, and width 2½ feet: the openings in the platform, from one ladder to the other, 18 by 12 inches; the thickness of the vein of ore varies considerably, sometimes being 8 feet, at others a few inches only. The veins do not incline much from the perpendicular, and consequently the levels are driven 6 feet high, and the ground above is worked afterwards. The ore is sometimes found nearer the surface than the adit level; but in general it is worked from 20 fathoms from the surface, to the 260 fathom level below the adit, the deepest point being nearly 300 fathoms from the surface.

In the large copper mines of the Levant in the western district, the height of all the levels is 6 feet, and from thence to the next level 10 fathoms or 60 feet; the thickness or width of the whole vein, where the ore is found, is on an average about 4 feet. The vein, almost perpendicular, having a small declination only, is worked by the side at first, and taken down afterwards. The adit or sea level is 30 fathoms under the surface, and the ore in work from 70 to 230 fathoms below the adit.

In the Eastern Cornwall district, the Fowey Consols copper mine is the most considerable; the smallest height of the levels is not less than 6 feet, and often 7 feet or more, where air-pipes are required for ventilation. There are no horseways in these Cornish mines; the twenty lodes vary in thickness from 8 feet to only a few inches. When the lodes are perpendicular, and of a sufficient size for the levels to be driven, they do not cut away any of the overlay or underlay, as the lode is very rarely perpendicular. The air of these shafts and levels is more condensed than that on the surface, with a temperature higher in proportion to the depth. There is no reason to believe that any gas except carbonic acid is generated from the strata in these mines: where they have been carried beneath beds of alluvium, which are periodically submerged, some of the inflammable compounds of hydrogen are at times emitted. The natural temperature at different depths, and in different strata, is given by Mr. Henwood, who personally inspected 200 mines in Cornwall and Devon, and made several hundred observations on the temperature of the streams of water which flowed from the unbroken rocks.

Depth in Fathoms.	In Slate.	In Granite.
Surface to 50	57° Fahr.	51·6°
50 to 100	61·3	55·8
100 to 150	68	65·5
150 to 200	78	
200 and upwards	85·6	81·3

When work is carried on, there is of course a rapid exchange of oxygen for carbonic acid, by means of the respiration of the miners, the burning of candles, and the blasting

which takes place; when the gases generated by the explosion of gunpowder are diffused a thick smoke fills the shaft or level. The following analysis shows the extent of impurity of the air in the places in which the men are employed.

From eighteen samples the summary of the analysis was, oxygen 17·067, carbonic acid ·085, nitrogen 82·848, and in one instance the quantity of oxygen was reduced to 14·51, and in another the carbonic acid was 0·23. These results exhibit a lessening in the proportion of the vital ingredient of the air from its usual per centage, 21, and an increase in a directly noxious ingredient, carbonic acid gas, from 0·05, its ordinary amount, calculated to produce effects sufficiently injurious to those who for hours together inhale such a fluid.

Ventilation is produced by the sinking of various shafts at short intervals, beneath the lowest levels, and establishing free communication between them as speedily as possible. But no method hitherto introduced is adequate to maintaining the air in a state of purity; every mine is more or less wet, as it constitutes a receptacle for the waters permeating the strata through which it passes:

The Adit is the drain through which the water, lying above its level, and a great part of that raised by machinery, is discharged. One or more of the deepest shafts are appropriated as wells, from whence the water is raised by steam power, a preliminary process involving the greatest difficulty and outlay connected with the working of many mines. Such a well or pit at the bottom of the engine shaft is called the *sump*, and when the water has been so far removed as to admit of the workings being carried on in the lowest levels, it is said to be *in fork*. Mines in slate are generally more wet than those in granite.

When the mine is situated near the coast, its drain or adit generally opens on the surface, at a point a little above the level of the sea, and when inland the deepest valley in the neighbourhood is the place of its discharge. In some cases a large common adit has been driven a little above high water into the centre of an upland mining district, and the separate adits of the several mines opened into this general drain. In many mines a large quantity of water is constantly poured through the interstices and fissures of the strata, and it is often at a temperature so much lower than that of the air in which the miners are at work, that they are subject to very serious chills from this cause.

Ladders are the universal means of ascent and descent, the distance between the levels being generally 60 feet; a single ladder in former times reached from one to the other, but the most usual length at present is from 4 to 5 fathoms. In the perpendicular shafts the inclination is commonly such that the ladder may nearly traverse the breadth of the shaft; from 18 to 21 inches in the fathom is the inclination which experience has determined to be the best calculated to facilitate the progress of the miner, being that which enables him to stand upright on the ladder with the leg clear from the stave above, so that the effort is divided between the upper and lower extremities. The distance between the staves is generally 12 inches, in some old ladders they were 14 inches apart, but 10 inches is found the best for facilitating the climbing, by which one-fourth of the labour is estimated to be saved. The staves are of wood, though iron is in some instances preferred, in others it becomes slippery and rough from the corrosive action of water impregnated with copper, &c. Each ladder usually terminates on a *sollar* or platform, which leads to that below, which is generally placed parallel to that above; trap doors are provided over each man-hole to prevent accidents, but closing them obstructs the free ventilation.

The principal tools used by the miners are *picks* for working the rocks, *borers* and *mallets* for making the holes for blasting; these are often sent up and down in the bucket (*kibble*) in which the ore or rubbish is drawn to the surface, but the miner very commonly carries with him from 10 to 20 lbs. weight of tools, there being a constant necessity for hardening and sharpening them, which is done at the smith's shop; in some mines this is established underground, which is very advantageous, the weight of coal sent down being only one-fortieth of that of the tools sent up.

The dress of the miner is of woollen, consisting generally of trowsers, shirt, and jacket; he does not wear stockings, but puts on a pair of thick shoes, and covers his head with a strong felt cap, hemispherical on the crown, and broad-brimmed, about 2 pounds in weight; on this he usually sticks his candle by means of a lump of clay, attaching another to a button. These habiliments are, unless the miner lives near at hand, usually kept at the mines in the changing-houses, where the ordinary dress is left until he comes up from his work.

The great body of the miners underground are employed in excavating the rock, whether for the sinking of shafts, the driving of levels, or the removing of the veins of ore, which operations require the almost constant application of the explosive force of gunpowder. The greatest part of the work consists in *beating the borer*, that is, in driving an iron cylinder terminating in a wedge-shaped point, by blows with a heavy hammer (mallet), whilst it is turned by another hand. The necessity or advantage of making the hole in a particular direction often constrains the miner to assume every variety of posture; he is even compelled at times to lie on his side. When the rock has been bored to a sufficient depth, the charge is introduced and rammed down with a

tamping iron, a particular clay being used for wadding, a certain length of safety fuse keeping up the communication with the powder; when fire is applied the miners retire till the explosion has taken place. It is not often that the safety fuse misses fire, but accidents now and then arise from its burning more slowly than usual, which may occur from too tight ramming down, when the impatience of the miner induces him too early to examine into the cause of the delay, and the explosion takes place before he withdraws. After the blasting the *pick* comes into requisition for the removal of the partially separated angular pieces of rock; in soft ground the use of gunpowder is only occasionally required. These works are done by the piece; the miner contracts to excavate the rock in a certain situation at so much per solid fathom; this is denominated *tut-work*; or he undertakes to excavate the vein, and to fit the ore for the market, at the price of so much in the pound of the sum for which the ore is sold; then it is called *tribute*. Both these contracts are to a certain extent speculative; but whilst the former involves only the uncertainty of the nature of the ground, which in these strata is not ordinarily great, the latter is dependent on the character of the vein, as well as on its size and richness, which are exceedingly variable in the majority of mines; the consequence is, that while the *tut-workman* receives pay approaching, in the regularity of amount, to that of the daily labourer, the *tributer* is on one occasion absolutely a loser, and on another receives a sum unusually large for a person in his rank of life; he is in fact a co-adventurer with the owners, but one who risks nothing but his time and labour.

The methods by which the contracts are let tends, however, to equalise, in a great measure, the average monthly earnings during periods of considerable length; at certain stated times, generally at an interval of two months, the work to be done in different levels is put up to be contracted for. Each place of work (*pitch*) requires a certain number of men and boys, determined by the agent, the partnerships between the individuals being entirely voluntary. The greater part of the men who are employed in a particular mine are generally present on these occasions; at any rate one of each party is there to compete for the contract. The agent, who acts as auctioneer, commonly standing in the window of the counting-house of the mine, names a particular place of work, as the 140 *West of Doctor's Shaft*; some one immediately names a price, and in a great majority of cases this is one of the party who has been working in the place in question, and no one underbids him, but the agent states a lower price, which is accepted. Where the contract is taken by the party which had it before, it is generally throughout the mining districts a rule not to disturb those who have been in possession of a *pitch*: it is the assurance springing from this, which sometimes induces a party of miners when a new *pitch*, one which has not hitherto been worked, is set up, to take it for nothing, or next to nothing. They expect to establish themselves in the mine, and on the next setting day, they probably obtain a remunerating price.

There is of course an opposition of interests between the owners, whom the agent represents, and the labourers, and the object of the latter is to make the former believe the ground harder, and the veins poorer than they are. He, on the other hand, forms his own judgment on these points by an accurate examination within a day or two of the *setting*, and fixes his price for the most part so that average wages may be gained by the men. It is clear, however, that where a *tribute pitch* is at present poor, he must be cautious in giving a higher price, as there is always a possibility of a rapid increase in the size of the lode, and the value of its produce. The contracts are generally good from one setting-day to another, or for two months; but longer terms are often given, where the work to be done is known to be of equable value.

The setting-day is usually the pay-day likewise; accounts are given to each party, stating the value of their work, and the deductions to be made from it. The sum due to the *concern* is received by one of its members, and divided afterwards among them. One considerable item in these bills is what is called the *subsist*, which is an advance made *on account* at the end of the first month of the contract, for the subsistence of the men and payment of the boys. Its amount is commonly determined by the value of the work already done: but in some mines the sum advanced is always nearly the same, and where the men are relied upon for continuing at their work, this pay is allowed for a number of successive months, until at length their contract becomes more profitable, and they are enabled to discharge the arrears.

The most common ore of copper is the yellow sulphuret (*bisulphuret*), or rather copper pyrites, which is frequently combined with stony matter, blende, galena, mundic, oxide of tin, wolfram, and other substances in a smaller degree. The existence of either of these is matter of consideration for the *smelter*, in making a proper mixture of ores for the furnace. The smelting of copper ores in the West of England has been entirely discontinued, it being found more profitable to send them to Wales, as a return freight for the ships bringing coals to the mines.

The Crushing Mill is not generally adopted on account of the difficulty of bringing the ore to exactly the proper size. The average quantity of copper contained in the ore is

rather less than 9 parts in 100; if it is pulverised too finely, which is difficult to prevent, especially when it is not very hard, there is a chance of loss in smelting, from the particles being carried up the chimney by the force of the draughts. For this reason copper ore, which has been pulverised in the stamping mill, generally sells rather lower than the other ores.

In tin and lead ores there is also danger from the same cause as well as some loss, as they contain about two-thirds of their weight of metal when they are put into the furnace. The other ores of copper are found in comparatively such small quantities that the large operation in preparing them for sale scarcely applies. The *Grey Ore*, chiefly a sulphuret with a small admixture of iron, is the second in importance, but relatively of rare occurrence. It requires no difference of treatment from that of the richer portions of the bisulphuret. The black ores, of which but a very small quantity is found (usually oxide of copper), are permitted to touch the water as little as possible, as they are often found in particles so fine as easily to be carried off by a small stream.

There is probably no metal which exists in so few varieties as tin: except a little *sulphuret*, which has been found in combination with sulphuret of copper, all the tin ore is in the state of oxide. The tin and copper are sometimes so intimately mixed in the ore, and it is so difficult to separate them, that it becomes a subject of debate whether it should be sampled as copper ore, or carried to the smelting-house as tin. The tin ores raised in the west of England are smelted there, and the metal is brought to different degrees of purity for various purposes.

The richest stream tin is not taken to the stamping mill, as it merely requires some reduction of size to prepare it for the furnace. Parcels may be frequently seen, the greatest part of which consist of small pebbles, just as they were found in the stream, which require little or no calcination. But with this exception *tin ore* is all subjected to the stamping mill. The ore is in itself so rich, and consequently so heavy, that it is easily separated from the stony particles by the power of gravity.

This mode would not be advantageous for the copper ores, as the trouble of effecting their separation would be far too great; none therefore of these ores are subjected to the stamping mill, except some of the *halvans*, which have been thrown aside from the other processes, to separate which pulverisation and subsequent dressing by water must be employed.

The tin ore, which has connected with it the largest quantity of copper and iron pyrites, naturally yields the greatest proportion of arsenic. Copper ore is calcined by partial decomposition, to get rid of the sulphur and arsenic contained in it, and tin ore to decompose the ores of other metals connected with it, and to expel the sulphur and arsenic they contain; afterwards the tin ores are taken to the stamps, and a series of washings succeed, sometimes 100, before they are prepared for the calcining furnace. The portion of copper ores subjected to similar processes is comparatively very small, simple selection and pulverising being the only preparation necessary.

In the preparation or dressing of the copper ores, the first step is the separation of the larger pieces raised from the smaller by a sieve called *riddle* or *griddle*. When this has been done, the process of picking the valuable portions of the latter from the worthless succeeds; and this is the work which female children are first employed upon, whilst some of the youngest boys are engaged in *washing up*, or cleansing the stones previously to this selection: this is done in wooden troughs, through which a stream of water flows immediately in front of the pickers. The girls are seated or half recline on a table, and a small heap of the mineral being thrown before them, they select and it put into a basket, or otherwise separate the valuable pieces, and throw back the others into what are called the boxes, whence they are wheeled by boys to a large heap, which is again subjected to examination. This picking is carried on under a shed (*hutch*), open on both sides, for the convenience of washing in front, and of the carrying away the rejected portion at the back.

The Riddling, mentioned as the first part of the separation of the larger from the smaller pieces of ore, is performed by girls of sixteen years old or more: the very large masses are broken or *ragged* by men; those somewhat smaller are *spalled* by stout girls with long-handled hammers, much in the way in which the larger pieces of stone are broken for the repair of roads. The *riddling* and *spalling* are performed in the open air.

The fragments are next to be *cobbed*; this process is performed by girls, who are seated a little above the ground with an iron anvil at their side; they break the stones with a short-handled hammer, to about the size usual in the repair of roads, rejecting as they proceed the worthless and very inferior parts. The stones of ore are now taken to be bruised or *bucked*, where the further reduction of sizes is effected by the mill, called a crusher or grinder, now employed in pulverising of probably full half the copper ores raised. The manual process of *bucking* consists of pulverising by a sort of combined movement of percussion and trituration the pieces of ore already reduced to the weight of an ounce or two, being chiefly those brought from the cobbers; this is done with a broad square hammer 2 or 3 pounds in weight, worked with both hands, or sometimes with one only, whilst the other is employed in sweeping the ore within convenient range; the bucker

stands by a sort of counter, having iron anvils let into it at intervals. The pulverised ore is allowed to fall on the ground, from which it is afterwards swept up and measured into barrows, for each of which a certain price is paid. The substitute for this method of pulverising copper ores is the crushing-mill; this consists of two parallel cylinders of iron placed nearly in contact, one of which is made to revolve, whilst the other is fixed so as only to yield to great pressure: the stones of ore thrown in from above are ground between these rollers, and a cylindrical sieve is placed beneath, which being inclined at an angle of 45°, and turning on its axis, allows the particles which have been sufficiently pulverised to pass through its holes, whilst the larger pieces fall out at the bottom and are returned to the mill. The working of this machine is attended with the suspension in the air of a great quantity of mineral dust, often of a very suffocating nature; when inhaled even cursorily it is found to produce ill effects upon the lungs; the ores are wetted for the purpose of lessening the escape of this dust, and any consequent loss. A further separation of the more valuable part of the pulverised ore is effected by the process called *jigging*, which consists of keeping the whole of the mineral particles suspended in water, for a time sufficient to allow of the subsidence of the more ponderous portion; this is done by the agitation of the water in the sieve in which the broken ore is placed; the more finely pulverised part passes through the interstices of the sieve, and the heavier pieces of larger size occupy the bottom, sufficiently separated to admit of the light and worthless stone being removed from the top with a piece of wood. The agitation of the water was formerly produced by hand labour, and in many instances boys are employed at this work: the jigger is obliged to bend forward over the water, across which he generally strides and shakes the sieve (usually 1½ or 2 feet in diameter) beneath the surface of the water; when the separation of the several portions of the mineral is judged to be effected, the sieve is lifted out and the refuse removed.

Machinery has superseded this process in a large proportion of the works: two methods are in use, by one of which a succession of sieves are kept in motion under water, by means of a connection with a water-wheel or steam-engine; and in the other, the water itself, in which a number of sieves are immersed, is kept in a state of agitation by the motion of a body in the centre. Whichever of these contrivances is adopted, the only manual operations required are the supply of the mineral, and the removal of the worthless portions from the surface. The inferior portions of the copper ores, from which the metalliferous particles cannot be extracted by the methods described, is subjected to the *stamping-mill*, as are almost all the ores of tin; the mineral is reduced by the action of these heavy hammers to a fine powder, which is carried by a stream of water through the perforations, made in a set of plates of iron surrounding the boxes in which the stamps work. A series of washings of this powder succeeds, the principle of which is the carrying off the lighter particles by a current of water of graduated power, and allowing the more ponderous to remain and subside. The number of these washings, amounting in some tin mines to about 100 from first to last, causes the employment of a large number of boys and girls. The operations called *trunking*, *buddling*, &c., chiefly fall to the lot of the former, together with the clearing out of the slime pits, in which the mineral mud is collected, and wheeling this slime for further dressing, all of which are carried on in the open air. The more delicate manipulations are generally intrusted to females: among these what is called *framing* in some districts, and *recking* or *racking* in others, employs a great number; in this the girl stands at the side of a very shallow wooden frame inclined at a moderate angle, and open at the foot: at the head of this, on a ledge more or less raised, a portion of the metalliferous mud is extended, and being divided by a light rake, a gentle stream of water is allowed to find its way through it, and to carry it gradually to the frame below; by a skilful direction of the current, the lighter portion is carried off at the bottom, and the heavier is thrown beneath the frame by tilting it into a vertical direction upon the pivot upon which it hangs, and throwing water with the shovel upon its surface to wash off any portion which might adhere to it. The tin ores, after these successive cleanings, are removed to the calcining furnace, and are subjected to several further washings: in some of these the girls sit within and at the lower part of a long wooden trough, and direct the gentle current of water with a light brush or feather over the surface of the ore.

Sampling is finally preparing and dividing the ores for sale: this division into separate parcels is done by females; the general heap, containing some hundred tons, is surrounded by a number of pairs of girls with handbarrows, which are filled from the edge of the heap by a party stationed round in a regular succession, directed by a girl appointed to the post; the barrows are then carried off rapidly, as the germs of a certain number of distinct parcels, and to each of these a barrow-full is added in regular order, so that the total number in every one is the same: those who fill the barrows exchange places after a time with those who carry them; the latter have during their turn by far the harder work, the barrows usually containing about 1¼ cwt.

Iron.—The ores of iron are extensively diffused throughout the mineral kingdom in

every part of the globe, and are found in small quantities in some animal and vegetable bodies, in several mineral waters, and in every soil; it is also met with in combination with sulphur and with several acids. It is of a bluish grey colour, and a dull fibrous fracture, capable of being brought to a brilliant polish; it is fusible at a white heat, is extremely ductile, but cannot be hammered into very thin plates. It is the most tenacious as well as the hardest of the malleable metals. It is oxidated by air and by water, and by many other acids; but air in a dry state, or water free from air and acid, exert but little influence over it; the rust being occasioned by an exposure to a moist atmosphere. It is easily moulded into any shape, drawn into wires of the greatest fineness and strength, rolled into sheets or plates, hardened or softened, welded by heat and rendered permanently magnetic, and converted into tools of every description; indeed it is scarcely possible to limit the various purposes to which it may be applied, and it may be justly considered as the most useful of all the metals: its specific gravity is 7·77. It is obtained in England principally from the carbonate of iron of the coal formation, which usually yields about 30 per cent. of cast metal, or sometimes as much as 40 per cent.

The carbonate of iron consists of two varieties, the *compact* and the *sparry*. The compact comprises most of the clay iron-stones, and those found in the coal measures of a flat spheroidal form; its colour is either a yellowish brown, brick red, or reddish grey, with a fracture close-grained; it yields a yellowish brown powder; it will not effervesce with either of the acids, and it has a slightly argillaceous smell when breathed upon. The slaty clay between the seams of coal affords abundant supply of this ore; it is frequently found in continuous beds, sometimes 18 inches in thickness. The sparry carbonate of iron has a lamellar fracture, a yellowish grey colour or brownish red; it slightly effervesces with nitric acid, and changes to a reddish brown: its primitive form, when crystallised, is an obtuse rhomboid, and the crystals often contain quantities of carbonate of lime. This ore is found in the mountains of gneiss, in combination or mixed with quartz, copper pyrites, oxide of iron, and carbonate of lime of different varieties. Natural steel is produced from it, and in England and Scotland it produces from 30 to 33 per cent. of cast metal.

The richest specimen, analysed by Dr. Colquhoun, which had a specific gravity of 3·05, gave, in 100 parts,

Carbonic acid	35·17
Protoxide of iron	53·03
Lime	3·33
Magnesia	1·77
Silica	1·4
Alumina	·63
Peroxide of iron	·23
Carbonaceous matter	3·03
Loss	1·41
	100·00

and its contents in metallic iron were 41·25.

Three-fourths of the iron manufactured in Great Britain is obtained from the coal fields of Dudley and South Wales; the former is very favourably situated, as the ore, the limestone flux, and the clay for making fire-bricks, are all obtained with the coal. At Merthyr Tydvil in Wales, the iron-stone is found in abundance in about sixteen beds of slate clay, in nodules of various size, both below and above the coal seams; in this district there are upwards of thirty blast furnaces, and the iron is chiefly converted into bars.

Of the Assay of Iron Ores.—To obtain all the iron contained in the ore, it must be first deoxidised, and the temperature so raised that the metals and earths will melt, when a button of iron will be found at the bottom of the crucible; to effect this, and to overcome any refractory earth, borax is usually added as a flux, taking care that the ore is finely powdered before being mixed with it; it is then placed in a crucible which is previously coated or lined with hard-rammed damp charcoal dust. The ore and flux is also covered with the same material. The crucible is then closed with a well-luted lid and fire-clay, and placed in a furnace, where the heat should be moderate at first, in order that the moisture of the damp charcoal should be slowly passed off, and the deoxidation completed. This is effected within the hour, when more fire is applied until a white heat is obtained, which is kept up for a quarter of an hour; the crucible being then allowed to cool, the button of cast-iron is weighed, and the result denotes the quality of the ore from which it has been obtained. This method of assaying is called the dry way, and requires a temperature of 150° of Wedgewood.

To effect the assay in the *humid way* 100 grains of the ore, finely powdered, are digested with *nitro-muriatic* acid, when, of the numerous compounds mixed with the iron, silica or alumina will alone be thrown down. Any effervescence that takes place in the cold dilute

indicates by the loss of weight the quantity of carbonic acid gas which has escaped. The acid contents are then evaporated to dryness and digested in water, when the silica is alone found insoluble. The solution somewhat acidulated, and oxalate of ammonia added, the lime is precipitated in the form of an oxalate. Alumina and the oxide of iron are also precipitated by ammonia. The manganese may be thrown down by hydrosulphuret of potash, and the magnesia by carbonate of soda. The red oxide of iron contains 69·34 of metal, and 30·66 of oxygen.

To ascertain the quantity of iron contained in 100 parts without reference to the other materials comprised in the ore, a more simple method may be adopted. Hot nitric or muriatic acid is poured upon the ore, the solution filtered, and supersaturated with ammonia, when the iron oxide and alumina are alone thrown down. This red precipitate, digested with potash lye, gives the oxide of iron nearly pure.

Native iron is occasionally found, and is considered as of meteoric origin, in consequence of its containing a small quantity of nickel, the usual alloy of meteoric stones.

Iron and Oxygen.—Heat, air, and moisture, have the effect of oxidising iron, and converting it, according to circumstances, into either a protoxide or peroxide, and the two latter are salifiable bases.

Protoxide of Iron is seldom found pure; it is of a dark colour, and usually contains a small quantity of the peroxide; it is obtained by burning iron in oxygen, which when heated red-hot drops in the state of oxide. It is insoluble in water, tasteless, and of a black colour. Its equivalent is 28, and it contains—

Iron	1	28	77·6
Oxygen	1	8	22·4
	1	36	100·0

Peroxide of Iron is in the state of a red powder, when sulphate of iron is decomposed at a very high temperature; the colour varies according to the method adopted to obtain it; sometimes it is of a yellow brown, which acquires a darker tint by heating. Iron rust consists of the peroxide in union with water, and traces of carbonic acid and ammonia are found in it, the acid being derived from the air, the ammonia from the nitrogen of the air combining with the hydrogen of the water.

Iron	1	28	70
Oxygen	$1\frac{1}{2}$	12	30
	1	40	100

Iron and Carbon.—Cast-iron and steel are bodies which contain more or less carbon, and, as already observed, it is from the carbonates of iron in a native state that the chief metal is obtained. The clay iron ore of our coal districts is an impure protocarbonate of iron.

The Protocarbonate of Iron consists of

Protoxide of iron	1	36	62
Carbonic acid	1	22	38
	1	58	100

Iron unites with chlorine in two proportions, viz. the protochloride and a perchloride.

Native Sulphurets of Iron. — Among these are the *magnetic pyrites*, which is a protosulphuret of iron, and the common pyrites, which is a bisulphuret, crystallised in a variety of forms, having their origin in a cube; their colour is a brass yellow; they are used to produce green vitriol, or sulphate of iron, and as a source of sulphur in the production of sulphuric acid.

The Bisulphuret of Iron contains

Iron	1	28	46·6
Sulphur	2	32	53·4
	1	60	100·0

Sulphates of Iron are used in the preparation of ink, Prussian blue, peroxide of iron, and carbonate of iron.

Protophosphate of Iron is found native in the state of a blue earthy powder, and sometimes in prismatic crystals; it is said to contain

Phosphoric acid	31
Protoxide of iron	41
Water	28
	100

Iron combines with cyanogen, and forms several important compounds, uniting in various proportions with other bodies. *Prussian Blue* is a ferrosesquicyanuret of iron, and has a peculiarly rich colour, of an intense blue with a copper tint on its surface; it is insoluble in water, in alcohol, and in dilute acids; the anhydrous variety consists of

Iron	7	196		45·5
Carbon	18	108		25·2
Nitrogen	9	126		29·3
	1	430		100·

Alloys of Iron. — Iron and potassium form a white soft alloy, which effervesces in water; that of iron and manganese is white, hard, and brittle, and is said to give a peculiar character to steel.

Salts of Iron are generally soluble in water, and the solution by exposure to the air becomes of a reddish brown; with ferrocyanuret of potassium, a pale or deep blue precipitate; and with the hydrosulphuret of ammonia a black precipitate.

The Persalts of Iron, as the permuriate and the persulphate, furnish a red precipitate, when the solutions are concentrated, upon the addition of sulphocyanic acid and the soluble sulphocyanates: none of the metals precipitate iron in a metallic state, zinc and cadmium excepted.

The weight of a cubic foot of cast-iron is 450·5 pounds avoirdupois, and of wrought 468·8 pounds, the weight of a cubic inch of the former being ·260 pounds, and of the latter ·281. It has been found that 93,000 pounds upon a square inch of wrought iron is sufficient to crush it, and that it will bear 15,000 pounds without any apparent change in its particles.

The quantity of pig-iron, manufactured in South Staffordshire in the year 1839, was estimated by Mr. Mushet as amounting to 346,213¾ tons, and in Shropshire 80,940 tons, being together nearly two-thirds of the whole quantity made in the United Kingdom. The materials for its manufacture are coals, ironstone, and limestone; the first, when intended for the cold-blast furnace, previously to its application, is made into coke; the ironstone undergoes roasting and calcining, and the limestone is broken into small lumps: after these operations they are mixed, or thrown into the blast furnace, in certain definite proportions.

The Coke is made by burning the coal in large heaps 4 or 5 feet high in the open air, the pieces being placed side by side, care being taken that they lie sufficiently loose near the ground to admit of a free current beneath them; these heaps contain as much as 20 or 21 tons. In some parts of Staffordshire, a brick funnel 2 feet in diameter, with occasional side apertures, is carried up to the height of 4 or 5 feet, and around which the coal or slack is heaped and continually watered. After the fire has been burning for 4 days, the coke is sufficiently made, and water is thrown over it to extinguish the fire and carry off the sulphur: 2 tons of coal so treated produce 1 ton of coke. In Shropshire the heaps do not generally contain more than 13 or 14 tons, and are suffered to burn 10 or 12 days, when a light blue lambent flame makes its appearance; the sides are covered with wet coke dust, and afterwards the top.

Calcining the Ironstone. — The ironstone in Staffordshire and Colebrook Dale is argillaceous. In some pits it is in bands 1, 2, or 3 inches thick, with measures of indurated clay, perhaps several feet thick, between; in others it is in boulders distributed through a bed of indurated clay, or of clay and sand. The boulders vary in size from that of a small apple to masses weighing many hundred weight. The usual form is that of a flattened spheroid; after the ironstone is taken out of the pit, it is laid in heaps exposed to the sun and air, for the purpose of evaporating as much of the water as possible. Before calcination the larger boulders are broken into pieces about the size of a man's fist, that the fire may act equally on all.

The ironstone is burnt on the ground like the coke, a layer of coals of several inches in height is laid down with the points touching the ground, so as to admit the air below; upon this is a layer of ironstone, then another of coals alternately, until the heap, becoming narrower with every layer, terminates in a point, after which small coal is spread over the whole, and fire is introduced at the bottom: this gradually spreads along the ground, penetrating upwards through the whole heap, and lambent flames are seen issuing between the pieces of the ironstone; in ten or twelve days the operation may be completed, and the ironstone being cooled is ready for the furnace.

The effects of calcining the ironstone are, to drive off first the remaining water, which would materially diminish the quantity of iron produced in the furnace, and injure its quality; secondly, the sulphur, which would produce the same effect; thirdly, the carbonic acid, which adds considerably to its weight, as it does to that of chalk or limestone. If the fire be continued too long, the ironstone, and all metals similarly treated, imbibe oxygen, and its quality is injured.

Blast Furnace generally resembles externally a round tower, or it is square at the bottom, and circular at the upper part; occasionally it is entirely square, but in either case its internal construction is the same. The exterior of the roof is flat, and from its centre rises a cylindrical structure, which serves as a chimney, from 20 to 25 feet high; it has an opening at the side called the filling place, into which the *coke*, *ironstone*, and *limestone*, are thrown. In many furnaces the external wall round the top is raised 10 or 15 feet higher than the floor, to protect the people employed from the cutting blasts of the wind. In Staffordshire, when the ground is level, the blast furnaces rise like the towers of an ancient castle, and the ascent to the top is by an inclined plane; the materials and the fillers are sometimes hoisted by the steam-engine, working ropes over a pulley at the top.

In Shropshire advantage is often taken of the difference of level of the ground, and the furnaces are built on the lowest part, so that the top may be even with the surface above; by such an arrangement the materials can be wheeled and thrown into the furnace without any difficulty.

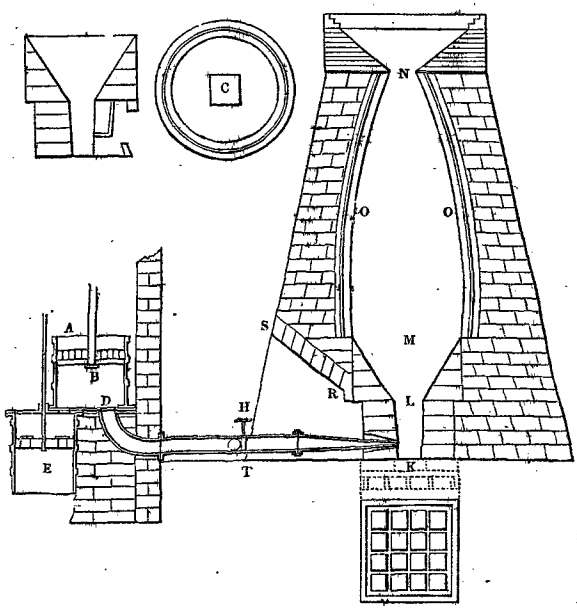


Fig. 586. SECTION OF IRON FURNACE.

In these furnaces A represents the regulating cylinder, 8 feet in diameter and height; B, the floating piston loaded with weights, proportionate to the power of the machine; C, the valve, 26 inches long and 11 inches wide, by which the air is passed from the pumping cylinder into the regulator: D, the aperture by which the blast is forced into the furnace, its pipe being 18 inches in diameter; the wider this can be made the less is the friction, and the more powerful the blast; E is the blowing or pumping cylinder, 9 feet high, and 6 feet in diameter, the piston within it having a stroke of from 5 to 7 feet; F, the blowing piston with its valve or valves, of which there are sometimes several distributed over the surface of the piston, the area of each being proportioned to the number; G is a pier of stone or masonry supporting the regulating cylinder, to which is attached the flanch and blowing cylinder; H is the safety-valve or cock, by the simple turning of which the blast may be admitted to or shut off from the furnace, passing to a collateral tube on the opposite side. I, the tuyere, by which the blast enters the furnace; the end of the taper pipe which approaches the tuyere receives small pipes of various diameters, from 2 to 3 inches, called *nose pipes*; these are applied at pleasure, as the strength and velocity of the blast may require. K, the bottom of the hearth, 2 feet square. L, the top of the hearth 2 feet 6 inches square. K, L, the height of the hearth, 6 feet 6 inches; L is also the bottom of the boshes, and where they terminate of the same size as the top of the hearth, only the former is round and the latter square. M, the top of the boshes, 12 feet diameter, and 8 feet perpendicular height. N, the top of the furnace at which the materials are charged, commonly 3 feet diameter; M N, the internal cavity of the furnace, from the top of the boshes upwards, 30 feet high; N K, total height of the internal parts of the furnace, 44½ feet. O O, the lining; this is done in the nicest manner with fire-bricks made on purpose, 13 inches long and 3 inches thick. P P, a vacancy round the outside of the first lining, 3 inches broad, and filled with coal dust; this space is allowed for the expansion which might take place in consequence of the swelling of the materials by heat when descending to the bottom of the furnace. Q Q, the second lining, similar to the first. R, cast-iron lintel, on which the bottom of the arch is supported. R S, the rise of the arch; S T, the height of the arch on the outside, 14 feet and 18 feet wide. V V, the extremes of the hearth, 10 feet square; this

and the bosh-stones are always made from a coarse-gritted freestone, whose fracture presents large rounded grains of quartz, connected by a cement less pure. The height of the entire furnace is *55* feet, and its diameter at bottom 38 feet.

The cost of a pair of blast furnaces in the Dudley district is about 1800*l.*; when 40 feet in height they require for their construction 160,000 bricks, 3900 fire-bricks, and 825 boshes. A furnace 50 or 60 feet in height will produce 60 or 70 tons of cast-iron per week; from 50 to *55* feet high, 60 tons; and two of *45* feet in height together, 100 tons. 3½ tons of coal, including the coal of calcination, are required to obtain a ton of cast-iron, and the workmen's wages amount to about *15* shillings; 14½ tons of coke, 16 of roasted ore, and 6¾ tons of limestone, being thrown into the furnace every 24 hours, allow a run of 7 tons of pig-iron every 12 hours. In many parts of Wales these furnaces are of much larger dimensions; that at the Plymouth iron works at Duffryn, near Merthyr, is 18 feet in diameter in the boshes, and 10 feet at the top or filling place, the height being 40 feet; it contains 7000 cubic feet, and when at work 150 tons of ignited materials for the smelting of the iron. In some of the largest furnaces 20,000 cubic feet of atmospheric air is forced into them every minute, by a pressure of 1½ lb. upon each square foot: their form varies in different districts, and when built against a side hill they have a flat wall, and the blast is admitted at the front.

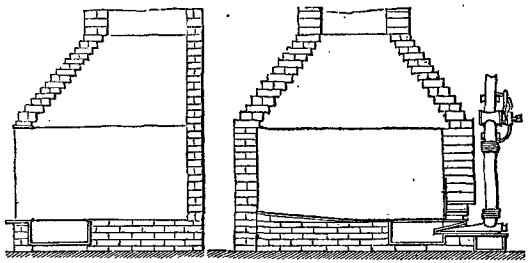


Fig. 587. SECTIONS OF IRON FURNACE.

The air apparatus is put in motion by a steam-engine, and the noise may be heard for many miles; the rod is made to force down the piston to the blowing cylinder, E, when two valves open, which allows the air to pass above the piston; by drawing it back the valves are shut by the pressure of the air above them, which being brought into a smaller space forces open the valve: as the piston rises air rushes into the vessel, and as the piston begins to descend, the valve is shut close by the force of the air. The heavy weights upon the piston now press it down, and force the air through the opening, and along the pipe with great violence into the furnace, with a constant and unintermitting stream. The air in the furnaces becomes very much heated, and passes up with great force through the materials, which by the heat are gradually melted, and slowly subside downwards, whilst fresh materials are put on at the top; about 36 hours is the time that it takes for a charge to get down to the hearth. Instead of the regulator, just described, several furnaces have a large vessel or a reservoir, made of plates of wrought-iron in the form of a cylinder, rounded at each end; the usual length is about 20 feet, and the diameter 8 feet. The air is forced into this precisely in the same way as in the vessel, and passes from it in a continuous and powerful stream into the blast furnace. The diagram shows only one air-blast directed towards the furnace, but in practice there is one from the other side, and generally another from the back of the furnace; the melted metal is let out from the front; a roof over head shelters the men engaged under it in the operation of casting; this is called the *casting-house.*

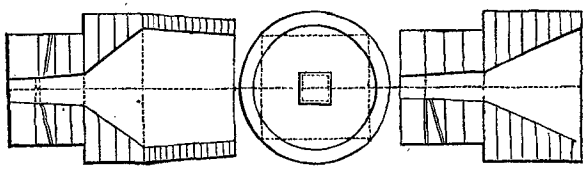


Fig. 588. PLANS OF IRON FURNACES.

The *hot blast* has been used with effect in Staffordshire and Shropshire; the general principle is, that instead of forcing the air into the blast furnace at the temperature of the atmosphere, it is previously raised to from 600° to 700° Fahrenheit by traversing a number of tubes which pass through a large fire made in a building at the back of the furnace. In practice the air is considered sufficiently hot when a jet striking against a piece of lead will melt it and cause it to fall in drops.

The effects of this invention in the iron trade have been very great: the operations of the furnace go on more rapidly, a greater quantity of iron is made from the ironstone, and there is a saving in fuel and limestone; raw coals may also be used instead of coke, which diminishes the expense.

In Staffordshire some hot-blast furnaces are worked with raw coals only, but in others a

mixture of two parts raw coal and one part coke is preferred. At those of Woombridge in Shropshire, the proportion is half coal and half coke; but even this is a great advantage. The iron produced by the hot-blast is not only less expensive, but for some purposes it is infinitely superior, for instance in fine castings, ornamented on the surface with delicate figures: when poured into the moulds it will enter into every line, however fine, almost like a Daguerreotype. For all articles, on the contrary, that are made by passing wrought-iron through the rollers, a stronger iron is better adapted.

In the districts of Staffordshire and Shropshire about one-third of the furnaces are blown by the hot-blast, and two-thirds by the cold blast: that part of a furnace which first requires to be repaired is the hearth, or lower part of the interior, into which the iron glides down from the melted materials. The hearth is made of sandstone, which resists heat; the most noted quarries of which in Staffordshire are at Gornal, about two miles from Dudley, and belong to the geological formation called the millstone grit. A furnace may require to be renewed in four years, and sometimes it may last seven or eight. A new furnace takes considerable time to dry thoroughly, and afterwards to heat, and then to be gradually charged with materials, ironstone, limestone, coke, or coal, so as to bring it into a proper state for the making of iron. When it is intended to discontinue a furnace, it must be blown out, as it is called, for if the blowing were suddenly to cease, the melted and half-melted materials would all vitrefy into one solid mass, and adhere to the sides of the furnace, which would involve the taking it down: hence it becomes necessary to continue putting on fuel and blowing until the whole contents has descended in a melted state to the bottom, and been let off. A furnace in full operation is charged by a set of hands, consisting of men, young people, and boys: the boys fill coke into baskets or barrows, and ironstone and limestone into what are cal ed boxes, though they resemble baskets. The young persons and men convey these materials to the filling place at the top of the furnace, and a certain proportion of each is thrown in, according to the orders given from time to time; to ascertain the proper quantities, an acquaintance with the peculiar qualities of those found in the district is necessary. A skilful and trustworthy person is required to superintend the weighing of the ironstone and limestone, for which proper machines are provided; for the coal or coke the eye is sufficient. There are generally two furnaces together, sometimes three, and when one is charged the people proceed to the other; they have never many minutes to rest, until after 4 or 5 o'clock in the afternoon, when the furnace is usually quite full; the blast is then stopped for a time, until the melted iron and cinder be let off. In about ten hours, sometimes a little more, a hole is bored in the sand and clay at the bottom of the hearth; the liquid iron flows out, and runs into a broad mould, with a number of smaller on one side, prepared for it in sand, on the floor in front of the hearth; these moulds are called the sow and pigs, and in conformity with this expression the iron is called pig-iron, and also crude-iron. Sand is sprinkled over it to prevent its cooling too rapidly, which would injure its quality. The cinder or liquid mass, composed of the clay and lime, with silex and a portion of iron, is then let off, and flows round a piece of iron, by which it is held fast when cooled, and to which a crane pulling a chain is attached; the whole mass is hoisted upon a waggon, and carried off from the surface to the further part of the cinder hill. If intended to be used as road materials water is thrown on it before it is quite cooled, and it readily breaks. The cinder has to be let off several times in the course of the twelve hours, generally every hour and a half, or every two hours; in some furnaces it is allowed to keep continually running off. The furnace-master observes from time to time the appearance of the melted cinder, and from it he is able to ascertain the condition of the furnace, and gives his orders accordingly, as to the proportion of the several materials. The people are relieved every twelve hours; the day set takes the nightwork every alternate week; the change is effected by the set at work during the day on the Sunday continuing all night till 6 o'clock on the Monday morning, that is called the double turn.

Moulding and Casting.—The pig-iron is found to be of various qualities, dependent on the quantity of carbon which has entered into combination with it during the process of smelting. The iron called No. 1. in commerce is highly carbonated, the most fusible of all, and most fluid when melted, and therefore the best adapted for fine castings, giving a smooth surface, and filling up the finest parts of the figure moulded. That called No. 2. is less fluid when melted, but better adapted for articles requiring strength and durability. The No. 3. is used for castings where very great strength is demanded; it may also be made into bar-iron. In order to be made into articles of cast-iron, the pig-iron has to be melted a second time. Moulds in the form of the articles to be cast are made of a mixture of sand and clay in boxes, laid on the floor of the foundery: the iron is melted in a furnace, let out into large pans, and then carried and poured into the moulds and left to cool. A great deal of casting is made from the iron as it comes from the blast furnace, as water-pipes, rails for tramways, broad flat pieces of iron for the flooring in front of the iron furnaces, &c. &c.

Refining of Iron.—The furnace is generally small, being about 3 feet square at the base in the inside; the bottom is of hearth brick, and the front, back, and sides are of cast-iron,

made hollow, so as to allow of a constant stream of water flowing through them to resist the heat of the iron; holes in the sides admit blasts of air, in the same way as in the blast-furnace. The pig-iron is laid in the refinery with the coke, and blasts of air passing through the flames are dashed against it, and the iron is melted; in about two hours or less, the metal is ready to be let off into a mould. In the process of refining a portion of the worst parts of the iron is left behind; the chemical change is effected by a separation of a part of the carbon united to the pig-iron; when cooled the iron is broken into pieces of a manageable size. Much less iron is now melted in the refinery than formerly, a method of converting pig-iron into malleable iron having been discovered without refining, which for many purposes answers exceedingly well, and is more economical.

Malleable or Wrought-Iron.—There are several kinds of pig-iron unfit for casting, but which undergo other processes in order to be made into malleable or wrought-iron, which is not brittle, like the former, and is so ductile that it can be drawn out to a considerable length, and to the fineness of wire. It may be welded, that is, two or more pieces may be hammered together into one: it is the iron ordinarily used by blacksmiths. For its conversion into malleable, the pig-iron has to be puddled, and then beat under the forge hammer, and passed through rolls or hollows in two iron cylinders, rolling round near to each other, which force it into long bars; it is then cut into pieces by a pair of shears, the pieces are laid over each other, heated in a furnace, and again passed between the rollers, by which it is forced into the shape intended.

Puddling Iron.—To undergo this process the iron is put into a furnace, the fire being at one end, and a chimney of sufficient height to produce a strong draught at the other. The flames raised by the draught are drawn upon the iron, pass on, and the heated air goes up the chimney. In some iron works each puddling furnace has a chimney to itself, and twenty or thirty or more such chimneys may be seen; but in others the air from all the puddling chimneys is conveyed to one more lofty than the rest, creating a still stronger draught. In about half an hour or less the iron becomes soft; it is then heated until it is fluid, when it soon begins to boil. The puddler now stirs it with iron rods, bringing every portion of the iron under the action of the flames: after a time the boiling and fermentation cease, and the iron becomes thick and adhesive. The puddler now divides it into parts, and rolls each part separately, until it has acquired something like the form of a ball, when the pieces are taken out to be subjected to the action of the great forge hammer. The puddle furnaces, the forge hammers, and the puddle rolls are employed day and night, on account of the great labour and expense of fuel in heating the furnaces if allowed to cool, in order to bring them again into a fit state for working: two sets of hands are consequently required, who take the night and day work alternately.

Forging the Iron.—The iron being in ill-shaped masses, called balls, one is taken from the puddling furnace, by means of a rod of iron, with a sort of hook at the end, and is then laid down to be forged, which is effected either by squeezing it forcibly between large pieces of iron, worked by the steam-engine, called the *squeezers*, or subjecting it to the blows of the forge hammers, by which means the cinder mixed up with the pure iron is driven off in a shower to a considerable distance, and a piece of iron is formed, somewhat resembling a brick, but from four to six times as large. This is immediately passed between the

Puddle Rolls, two huge cylinders, in which are grooves, similar in shape to the mass itself, so that when they revolve the iron passes through them, and is squeezed into a longer form. A boy on the side opposite to the workman lays hold with the tongs of the end of the iron, and places the end which comes out last against the upper cylinder, the motion of which carries it back again to the side where the workman called the roller stands, who then places the piece in the next groove, which as it passes through is still further elongated, and this process is repeated four times, when the iron becomes a bar, although a thick one. On a line with the two cylinders already mentioned are two others, their grooves being flat and broad, such as a bar may be laid upon, and there is a corresponding flat piece of iron in the upper cylinder to press upon it.

The bar is now under the care of a second workman, who places it in the groove, through which it passes, and is elongated. It thus goes on through successive operations, becoming longer and more slender, until at last it is 10 or 12 feet long. It is then withdrawn, and laid on a large flat piece of iron, and beaten by boys with wooden mallets, while it cools; others stand by the bar, in order to keep it straight.

The usual method until lately was to puddle only the refined iron, or that which had been smelted first in the blast furnace, and then again in the refining furnace. Of late years a practice has been introduced of puddling a mixture of pig-iron and refined iron, in Staffordshire called plate, thereby saving the expense of refining, and also the loss of metal always occasioned by that process; still greater economy is effected by dispensing with the refined iron altogether, the loss upon which amounts to about 12½ per cent., which added to the expense of refining will make altogether a difference of 2 pounds per ton. It is true that the iron so manufactured will not be so good, and may lose something more in passing through the rolls, but for most purposes it answers sufficiently

well; though there are many cases in which that made by the less economical process is indispensable.

Rolling Mills.—The iron having undergone so many operations, having been smelted from the ironstone, refined, puddled, forged, and drawn through puddle rolls, might be supposed to be brought to a perfect state of manufacture; but there is still another process before it is fit for sale and common use.

The puddle bars are cut into pieces of equal length by shears, made of hard steel and moved by the steam-engine, with apparently as much ease as if they were cutting paper: four or five, sometimes as many as seven or eight, of these pieces are laid upon each other and placed in a balling furnace, very similar to that in which it is puddled, and are heated by a hot blast, driven against them with sufficient force to render the iron soft, so as to be capable of welding or uniting together, but not to become fluid; they are then taken from the furnace, and passed between rolls, just in the same manner as in the puddle rolls, the inclosed space between the rolls becoming smaller and smaller, until the bar is drawn out to the intended length and size, when it is finished wrought-iron. This process is applicable to every variety of purpose, from the rails for a railway to the small bars or rods for making nails, plates for the boilers of steam-engines, and the various portions of iron boats or ships, and other things requiring great strength. Some of the plates are afterwards tinned for culinary vessels, &c., by being dipped into a solution of tin in sulphuric acid, which is called pickle; when withdrawn they are found coated with tin; the acid having a stronger affinity for the iron unites with it, and the tin is deposited on the surface. The plates are afterwards rubbed and polished.

Steel is a carburet of iron, and of great value, in consequence of its being readily tempered to any degree between extreme hardness to softness. These different states are produced by raising the temperature, and then suddenly plunging the metal into cold water, or some other fluid; the hardness is destroyed by heating to redness, and then leaving it gradually to cool. At a white heat it becomes less malleable than at a red heat, and brought to a very high degree it fuses, and returns to its original state of pig-iron. Its increase in weight is from 4 to 12 ounces per hundred weight; there are three different qualities, as natural steel, steel of cementation, and cast steel; the first acquires some peculiar properties from the manner in which the ore is treated.

Steel of Cementation, bar of blistered steel, is manufactured in bars, and none is superior to that made from Swedish iron; the furnace employed for this purpose has an hearth of an oblong quadrangular form, divided by a grate into two parts, on each side of which is a chest built of firestone grit; these are each from 10 to 15 feet in length, and from 2 to 3 feet in width and depth; the sides are 3 or 4 inches in thickness, and the space between them is about 12. These chests do not rest upon the sole of the furnace, but are so placed that the flame plays freely all round them; the heat is regulated by an opening in the arch, or sides of the furnace, which conducts to the chimney.

The breadth of the grate varies according to the nature and quantity of the fuel employed; the whole furnace is constructed under a conical hood or chimney, 50 feet high, which has a thorough draught, produced by numerous air-holes at the bottom of the grate. The furnace being prepared, bars of iron of a proper quality, a little less in length than the chests or troughs, are put upon the bottom, on which has been previously spread a layer of charcoal dust; layers of iron bars and charcoal are then alternately put in, and the whole covered over with clay to exclude the air, which, if allowed to enter, would destroy the process; the bars are not suffered to touch each other in the trough, and the fire is continued for three or four days, till the temperature of 100 degrees by Wedgewood is obtained, at which it is steadily maintained for six or ten days if necessary. When the cementation is complete, the workman draws out a bar, and examines the blisters on it: if not sufficiently changed, the air is again excluded, and the process continued, but if in the required state the fire is put out, and the steel is left to cool for eight days, when the process for making blistered steel is completed.

The blisters are formed by the bursting of vesicles on the surface, filled with carbon in a gaseous state; on the interior blistered steel is irregular in its texture, has a white colour like frosted silver, and exhibits crystalline angles and facettes, which increase in size the longer the cementation has been continued, or the greater the quantity of carbon applied.

The imbibing of the carbonaceous matter renders the steel unfit for any useful purpose, until it has undergone the operation of tilting, which is performed by submitting it to a powerful hammer, weighing 2 cwt., lifted by machinery, and giving from 300 to 400 blows per minute. Hammering improves the malleability, and renders the steel peculiarly adapted to the manufacturing of edge-tools and cutting instruments of all kinds; this property has acquired for it the name of shear steel.

Cast-steel is made from blistered steel broken into small pieces and packed in fire-clay crucibles, with a small quantity of powdered coke; the crucibles contain about 30 pounds of steel, and generally serve for three charges. They are placed in a furnace the

cavity of which is like a square prism lined with fire-bricks, and the smoke is conducted into a lofty chimney. Cast-steel will not bear more than a cherry red heat without becoming very brittle; it cannot be welded together, but will unite with iron through the intervention of a fine film of vitreous boracic acid, and the latter metal may be plated with cast-steel, by pouring the liquid steel from the crucible upon a bar of iron laid in a mould with the upper face polished; the adhesion becomes so perfect, that the two metals may be rolled out together, and instruments made of it will have the toughness of iron combined with the hardness of steel.

According to Mr. Mushet, carbon combines with iron in the following proportions to form the different carburets:

Soft cast-steel	$\frac{1}{120}$
Common cast-steel	$\frac{1}{100}$
White cast-iron	$\frac{1}{25}$
Black cast-iron	$\frac{1}{13}$

and the specific gravity of steel varies from 7·31 to 7·91, which is that of the best hammered: so great is the affinity of iron for carbon, that it will absorb it from carburetted hydrogen or coal gas, and thus become converted into steel.

Hardening Steel is performed by putting it into a charcoal fire, and when the metal has acquired a red heat, it is suddenly plunged into cold water; where these plates are required to be hardened, they are plunged into oil and tallow, or bees-wax and resin, as the water would render them too brittle, and cause them to crack.

Tempering is effected by again submitting the metal to the action of fire; as the heat increases it becomes softer, and when the requisite degree is arrived at, it is withdrawn and quenched in cold water. To an experienced workman, the degree of temper is indicated by the colour; for springs or where elasticity is the object, it is quenched when the colour assumes a fine blue: when a fine edge is required it is brought to a straw colour, whilst the back of the instrument is left blue. For magnets, the ends of the bar only are brought to a blue colour, as the harder the whole bar is left the better is the magnetism retained, although communicated with more difficulty in the first instance. The heat required by Fahrenheit's scale to produce

Very pale straw yellow, was	430°
Light purple	530
Dark blue	570
Pale blue	590

and for all a free access of oxygen is required.

Alloys of steel with platinum, gold, and nickel, may be made when the heat is sufficiently powerful.

Founding or Casting of Iron.—Iron intended for the foundery receives a high charge of carbon, whilst the bar or malleable iron must be deprived of it; consequently a different process must be adopted in the manufacture of these two varieties: that intended for the whitesmith, as already described, is put into a furnace where it is exposed to air and heat only, without the fuel coming in contact with it; that for the foundery must be remelted in close contact with the fuel, and excluded almost entirely from the air; hence as it melts it takes up an additional quantity of carbon when cast into pigs. There are varieties of pig-iron; the grey, which is the best, another of a medium quality, and one which is not much superior to the forge-iron. The finest soft iron, when struck with a hammer, scarcely yields any sound, like a mass of lead; its fracture shows little lustre and is coarsely granular, whilst the inferior quality is very brittle, easily broken by the hammer, and gives out a sound like a bell; its fracture is shining and of a silvery whiteness, with no granular appearance. Iron which after casting is required to be turned on the lathe, filed, or drilled, should be of the purest quality: where, however, great strength is required, and the casting is to be used as when taken from the mould, the medium quality should be preferred; when it is to be applied to the ram of a pile-driving engine, or for an anvil, the third quality should be selected on account of its hardness. These three varieties of iron owe their qualities to the carbon, the best containing the greatest proportion; when this is running from the furnace, a large quantity of carburet of iron floats on its surface, denoting it to be a superior kind.

The Cupola and Air Furnace.—The first is used for small, the latter for large castings; the cupola requires a blowing machine of some kind, whilst the air-furnace has a sufficient draught created by means of a lofty chimney.

The open Sand Casting is applicable to flat plates, where one side is rough or uneven; the mould is made of sand of a peculiar kind, having its grains of an equal size, and not of a nature to vitrefy when highly heated; this is mixed with enough loam to give it when moistened the property of being moulded into the form required; it must also be sufficiently open to allow the escape of air or steam when the hot iron is poured into it.

The sand is usually passed through a sieve, and the surface made hard and level by continuous beating with a rammer, and then smoothed by a trowel: an edge of the same material to confine the casting is formed around it, by first laying laths of the thickness of the intended plate on the prepared bed, and then making the border or edge close to them; the laths are then removed, and the metal is poured into it. To prevent the casting from cracking as it cools, the moment it sets it is covered with a thickness of 3 or 4 inches of dry sand.

Flask or Box Castings require a more perfect model or pattern, which is usually made with boxes or flasks as they are termed, either out of wood or metal, put together in such a manner as to admit of being lengthened or shortened, and thus adapted by bolts and screw fastenings to an endless variety of forms and sizes. To make a casting two boxes are required; one is placed nearly on a level with the floor of the foundery, which is previously covered with sand and which forms the bottom: into this is put the moulding sand, which is well rammed in until a sufficient bed is made for the introduction of the previously prepared pattern, the centre line of which should about range with the top of the box; the whole is then filled up level with moist sand; this being pressed or rammed in and made smooth at the top, a quantity of perfectly dry sand is sprinkled over the surface, to occasion a parting or separation when the upper box is placed upon it; before this is filled, it is necessary to provide a vent for the escape of the air when the metal is poured in, and for the gate, a funnel-shaped channel that is to admit it: these two openings are preserved by placing two upright rods, slightly tapering, in the position required previously to filling the upper box with sand, which when rammed in, the box is to be lifted up and the pattern taken out, leaving its impression in the sand: this requires some skill and adroitness on the part of the workmen, who, by moistening the pattern with a little water, consolidate the sand immediately around it, and its liberation is rendered easy; should any breaking down of the sides of the mould take place, it must be repaired and made perfect. When the casting is to be hollow, as in cylindrical pipes or columns, it is necessary to introduce a core which shall correspond in dimensions with the void required, and the formation of this core demands considerable skill: a core barrel is made by twisting hay bands round an iron column, wetted and bound carefully from one end to the other; this is covered with well-tempered wet loam mixed with cow hair; were clay used it would burn into a brick or hard substance. When the core is thus prepared, it is rendered true by turning in a lathe, after which it is hardened in a stove or oven constructed of bricks with racks or shelves in it, and closed with iron doors: when the core is taken out, it is covered with finely ground coal-dust mixed with water, and when dried it is ready to introduce into the previously prepared mould; the heat of the metal poured in burns away the hay, which separates the iron core from its coating of loam, and when the iron begins to set the barrel is withdrawn, and the loam is scraped or chiseled out.

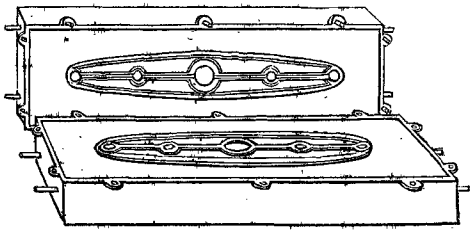


Fig. 589. FLASK CASTING.

The process adopted by John Weichard Valvasor, of Carniola, of casting statues very thin is given in the Philosophical Transactions, vol. xvi.: he first formed with good clay that endured the fire, and would not crack either in drying or burning, the figure or statue to be cast: when the model was quite dry, small holes of moderate depth were made over its entire surface, into which were placed small pieces of metal, to keep the core and mould from touching each other, or from falling together; a portion of the clay was then scraped away to as much as was intended to constitute the thickness of the statue, and the mould was placed in a furnace and heated red-hot: when cold, it was rubbed over with an earth used by the German potters to colour their tiles, resembling black lead, for the purpose of making the metal flow freely over it; yellow wax, mixed with pitch or resin, was then spread over, to the thickness of the metal to be given to

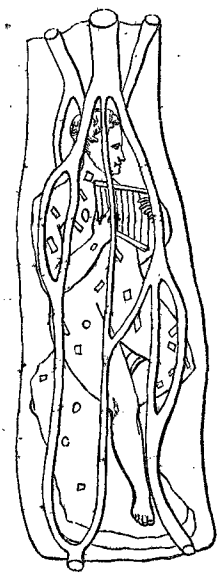


Fig. 590. STATUE CASTING.

the statue, which was performed with great care, and constituted a perfect model. The whole statue was then covered with smaller pieces of wax, in the direction intended for the channels of the metal, and of the necessary size; some being, as shown, considerably larger than the others; the whole was then coated with similar clay to that which formed the core. The great channels met at the top of the model, and formed apertures where the metal was to be poured in, but there were others provided by which the air could escape when the metal entered; at the bottom, or at the feet of the statue, a hole or two was left, where the great channels and waxen statue join; the wax forming the covering and the channels then ran out, and the mould was again submitted to a red heat: after this it was placed in a pit, and the same process adopted as for casting bells: to ascertain the quantity of metal, it is only necessary to weigh the wax, and compare it with the weight of metal to be used.

The statue of Lord Hopetoun, erected in 1834 at Edinburgh, was cast in a somewhat similar manner at the Royal Arsenal at Woolwich: a model made in plaster of Paris was covered over with a thin shell, composed of a number of pieces fitted nicely together, and which could be taken asunder, and after the model was removed again built up; the work was commenced at the bottom by covering a portion of the shell with sand to about 1 or 1½ inches in thickness, to which was added about 12 inches of plaster of Paris, which uniting with the sand, formed one block; the remaining part of the statue being completed with similar blocks, so arranged that they could be removed readily without disturbing the sand when the whole was finished: tubes were introduced with the plaster for the admission of the metal and for the escape of the air, and iron rings let into the blocks for the convenience of removing them. After the shell was complete, the whole was taken to pieces and removed to the casting pit, where it was carefully rebuilt, and the interior filled up with the material to form the core; it was then a second time taken to pieces, leaving the core of the shape and dimensions of the original statue; from this sufficient was scraped off to allow for the intended thickness of the metal; the shell was then put together as before, and a space left between it and the core for the operation of casting.

Green or dry Sand Castings.—In this process after the mould is made, the flask is placed in the stove, and there kept till the sand becomes perfectly dry: before it is used a fire of charcoal is made all round it to heat the sand previous to the metal being poured into it, the casting of which is always of a superior kind, in consequence of its not being cooled down too rapidly; all castings intended to be turned or filed should be made by this process, moist sand rendering the surface of the iron refractory and hard, as well as injuring its quality.

Loam work is employed where large cisterns or cylinders are required, and is effected without moulds or patterns, by modelling in loam the object required. Supposing the work to be that of a steam-engine cylinder, upon a plate of metal is built a mould with very soft bricks laid in beds of loam; this being completed, it is plastered over with loam and hair, about an inch in thickness, dressed perfectly even by a striking board, which works on a pivot, and traverses freely round the whole circumference: when dry, this is dressed over with a coating of coal and charcoal powder mixed with water.

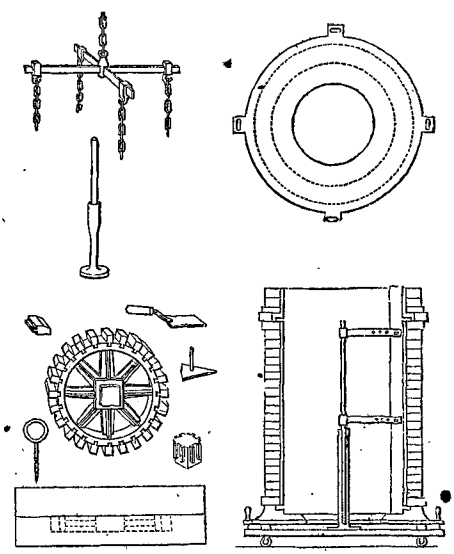


Fig. 591. LOAM WORK CASTING.

The intended thickness of the metal is then set out, and another coat of loam without hair is put on, and being worked true by the striking board, which is adjusted for the purpose, represents the place of the metal; any bands or ribs may be moulded upon it, by cutting out their profile in the striking board. When this coat is dry it receives its black wash, which prevents one coat of loam from adhering to the other.

Two semicircular plates of iron, having projecting arms and their insides made to the curvature, are now placed on the foundation plate; on these are built the external case of the mould, or the *jacket*, in two cylindrical halves, in the same manner as the core, but of

greater thickness: the several parts, when dry, are then easily removed by a crane, conveniently placed for the purpose, over a pit sunk in the ground deep enough to hold the casting. The two halves of the jacket are first removed laterally: the intermediate coat of loam which occupies the place of the metal is then broken away, and the core is lowered into the pit, by means of chains attached to the iron plate upon which the core was built. The two jacket pieces are then lowered and properly placed; the pit is filled up with sand solidly around it, and a cake of loam is placed over the whole, with the vent and gate holes; it is then ready for the reception of the melted iron, which is usually run at once from the furnace to the gate of the mould by means of a channel. To get the casting out of the pit the sand is first removed, the jackets broken to pieces, and then by means of the crane it is hauled up.

Great care is requisite in withdrawing the pattern from the mould, and if attention be paid by the pattern maker to form the lower portions a little smaller than those above, the difficulty will be lessened materially; regard must be had also to the contraction of the metal in cooling, which varies under different circumstances.

Of the Strength of Cast-iron Beams. — From grey cast-iron yielding so easily to the file when the external crust is removed, and being slightly malleable in a cold state, it is preferred by the engineer whenever iron is to be employed in construction; it is also less liable to fracture when it receives a blow than the hard metal: it has a granulated fracture, of a grey colour, with some metallic lustre, and is softer and tougher than the white cast-iron, which is, however, less liable to rust, and less soluble in acids; the white cast-iron, when cast smooth, makes excellent bearings for pivots or gudgeons, and is very durable; it may be employed where hardness is required, and brittleness is not a consideration. Soft grey iron was considered by Mr. Tredgold the best for constructions of all kinds, and his calculations were made upon it. When the weight laid upon an iron beam is distributed equally over it, the deflection is found to be the same as when five-eighths of the load is applied at the middle; in calculating, therefore, the strength of a brestsummer or any other beam, which is to be uniformly loaded, we must take only $\frac{5}{8}$ of the load as suspended to its centre.

In putting an inch square bar of cast-iron upon supports 3 feet apart it broke when 850 lbs. were suspended from the middle; and as cast-iron has its elasticity destroyed by about $\frac{1}{3}$ of the weight that will produce fracture, its permanent load should never exceed that amount, so that 850 lbs. may be considered the weight which an inch square bar of cast-iron will bear when its length does not exceed 1 foot.

The transverse strength of a beam is as its breadth to the square of its depth, and inversely as its length; so that a beam increased to twice its width will carry twice the weight; increased to twice the depth, it will sustain four times; thus by doubling its breadth its strength is doubled, doubling its depth its strength is quadrupled. A plate of cast-iron, 2 inches thick and 8 inches broad, will carry twice as much as one 2 inches thick and 4 inches in breadth, and the same placed on edge four times.

The strength of a rectangular beam of iron, supported at both ends and loaded in the middle, is found by multiplying 850 lbs. by the breadth and square of the depth in inches, and then dividing this product by the length in feet: the quotient gives the weight in avoirdupois pounds.

A bar of iron an inch in breadth, 4 inches deep, and 20 feet bearing, will sustain 680 lbs., for

$$\frac{850 \times 1 \times 4^2}{20} = \frac{13600}{20} = 680 \text{ lbs.}$$

The breadth of a beam is found by multiplying the length in feet between the supports, by the weight to be supported in lbs., and dividing this product by 850, multiplied by the square of the depth: the quotient thus found expresses the breadth.

$$\frac{20 \text{ ft.} \times 680}{850 \times 16} = 1 \text{ inch, the breadth required.}$$

The depth is found by multiplying the length by the weight to be supported in lbs. and dividing this product by 850 multiplied by the breadth: the square root of the quotient is the depth required,

$$\frac{20 \times 680}{850 \times 1} = 16, \text{ the square root of which is 4 inches.}$$

The weight of the beam may be found by multiplying the area of the section in inches by the length in feet, and that product by 3·2, which will give the weight in pounds; 3·2 lbs. being the weight of an inch square bar 12 inches long,

$$1 \times 4 \times 20 \times 3{\cdot}2 = 256 \text{ lbs.}$$

As iron differs much in its quality, the breaking weight of an inch square bar has been found to vary materially; some writers have therefore made their constant number 925 or 1000, instead of 850, which was preferred by Mr. Tredgold.

When the weight is placed on the axis of an upright column, or over the centre of the section of a short rectangular block of iron, to find the area that will resist any given pres-

sure; divide the pressure or weight in pounds by 15,000, and the quotient will be the area of the section of the block in inches.

For story posts of warehouses or other buildings, the following table was calculated by Mr. Tredgold.

A Table showing the Weight that may be placed with Safety on Cast-iron cylindrical Columns from 1 to 12 Inches Diameter.

Length or Height.	2 Feet.	4 Feet.	6 Feet.	8 Feet.	10 Feet.	12 Feet.	14 Feet.	16 Feet.	18 Feet.	20 Feet.	22 Feet.	24 Feet.
Diameter in Inches.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.
1	18	12	8	5	3	2	2	1	1	1		
1½	44	36	28	19	16	12	9	7	6	5	4	3
2	82	72	60	49	40	32	26	22	18	15	13	11
2½	129	119	105	91	77	65	55	47	40	34	28	25
3	188	178	163	145	128	111	97	84	73	64	56	49
3½	257	247	232	214	191	172	156	135	119	106	94	83
4	337	326	310	288	266	242	220	198	178	160	144	130
4½	429	418	400	379	354	327	301	275	251	229	208	189
5	530	522	501	479	452	427	394	365	337	310	285	262
6	616	607	592	573	550	525	497	469	440	413	386	360
7	1040	1032	1013	989	959	924	887	848	808	765	725	686
8	1344	1333	1315	1289	1259	1224	1185	1142	1097	1052	1005	959
9	1727	1716	1697	1672	1640	1603	1561	1515	1467	1416	1364	1311
10	2133	2122	2130	2077	2045	2007	1964	1916	1865	1811	1755	1697
11	2580	2570	2550	2520	2490	2450	2410	2380	2230	2250	2190	2130
12	3074	3050	3040	3020	2970	2930	2900	2830	2780	2730	2670	2600

A Table showing the Depths of square Beams or Bars of Cast-iron of different Lengths, to sustain Weights (its own being included) of from 1 to 500 Tons when supported at the Ends and loaded in the Middle; the Deflection not to exceed one-fortieth part of an Inch for each Foot in Length.

Tons.	*Lengths in Feet.*																		
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1	2·5	3·0	3·5	3·9	4·3	4·6	4·9	5·2	5·5	5·8	6·0	6·3	6·5	6·8	7·0	7·2	7·4	7·5	7·8
2	2·9	3·5	4·1	4·7	5·1	5·5	5·9	6·2	6·5	6·8	7·2	7·6	7·7	8·0	8·3	8·5	8·7	9·0	9·2
3	3·3	4·0	4·6	5·1	5·7	6·1	6·5	6·9	7·3	7·6	7·9	8·3	8·6	8·9	9·2	9·4	9·7	10·0	10·1
4	3·5	4·3	4·9	5·5	6·0	6·5	7·0	7·4	7·8	8·2	8·5	8·9	9·2	9·5	9·8	10·1	10·4	10·7	11·0
5	—	4·5	5·2	5·8	6·4	6·9	7·4	7·8	8·2	8·6	9·0	9·4	9·7	10·1	10·4	10·7	11·0	11·2	11·6
6	—	—	5·5	6·1	6·7	7·2	7·7	8·2	8·6	9·0	9·4	9·8	10·2	10·5	10·9	11·2	11·5	11·9	12·1
7	—	—	5·7	6·3	6·9	7·5	8·0	8·5	8·9	9·4	9·8	10·2	10·6	11·0	11·3	11·7	12·0	12·3	12·7
8	—	—	5·9	6·6	7·2	7·8	8·3	8·8	9·3	9·7	10·1	10·6	10·9	11·3	11·7	12·0	12·4	12·8	13·1
9	—	—	6·0	6·8	7·4	8·0	8·5	9·0	9·5	10·0	10·4	10·9	11·3	11·7	12·0	12·4	12·8	13·1	13·5
10	—	—	—	6·9	7·6	8·2	8·8	9·3	9·8	10·3	10·7	11·2	11·6	12·0	12·4	12·8	13·1	13·5	13·8
11	—	—	—	7·1	7·8	8·4	9·0	9·5	10·0	10·5	11·0	11·5	11·9	12·3	12·7	13·1	13·5	13·8	14·2
12	—	—	—	7·2	7·9	8·6	9·2	9·7	10·2	10·8	11·2	11·7	12·1	12·5	13·0	13·4	13·7	14·1	14·5
13	—	—	—	7·4	8·1	8·8	9·4	9·9	10·4	11·0	11·5	11·9	12·4	12·8	13·2	13·6	14·0	14·4	14·7
14	—	—	—	7·5	8·3	8·9	9·5	10·1	10·6	11·1	11·7	12·1	12·6	13·0	13·4	13·8	14·2	14·6	15·0
15	—	—	—	7·7	8·4	9·1	9·7	10·3	10·8	11·4	11·9	12·3	12·8	13·2	13·7	14·1	14·5	14·9	15·3
16	—	—	—	7·8	8·5	9·2	9·8	10·4	11·0	11·5	12·0	12·5	13·0	13·5	13·9	14·3	14·7	15·1	15·5
17	—	—	—	7·9	8·7	9·4	10·0	10·6	11·2	11·7	12·2	12·7	13·2	13·7	14·1	14·5	14·9	15·4	15·8
18	—	—	—	8·0	8·8	9·5	10·1	10·8	11·3	11·9	12·4	12·9	13·4	13·9	14·3	14·7	15·1	15·6	16·0
19	—	—	—	8·1	8·9	9·6	10·3	10·9	11·5	12·0	12·6	13·1	13·6	14·1	14·5	15·0	15·4	15·8	16·2
20	—	—	—	—	9·0	9·7	10·4	11·0	11·6	12·2	12·7	13·2	13·8	14·2	14·7	15·1	15·6	16·0	16·4
30	—	—	—	—	—	10·8	11·5	12·2	12·9	13·5	14·1	14·7	15·2	15·7	16·3	16·8	17·3	17·7	18·2
40	—	—	—	—	—	—	12·4	13·1	13·8	14·5	15·1	15·7	16·4	16·9	17·5	18·0	18·5	19·1	19·5
50	—	—	—	—	—	—	—	13·9	14·6	15·3	16·0	16·6	17·3	17·9	18·5	19·0	19·6	20·1	20·7
60	—	—	—	—	—	—	—	14·5	15·3	16·0	16·7	17·4	18·1	18·7	19·3	19·9	20·5	21·1	21·6
70	—	—	—	—	—	—	—	15·1	15·9	16·7	17·4	18·2	18·8	19·5	20·1	20·8	21·3	22·0	22·5
80	—	—	—	—	—	—	—	—	—	17·2	18·0	18·7	19·4	20·1	20·7	21·4	22·0	22·6	23·2
90	—	—	—	—	—	—	—	—	—	17·8	18·6	19·3	20·0	20·7	21·4	22·1	22·7	23·3	23·9
100	—	—	—	—	—	—	—	—	—	—	19·0	19·8	20·6	21·3	22·0	22·6	23·3	23·9	24·5
110	—	—	—	—	—	—	—	—	—	—	—	20·3	21·0	21·8	22·5	23·2	23·8	24·5	25·1
120	—	—	—	—	—	—	—	—	—	—	—	20·8	21·5	22·3	23·0	23·7	24·4	25·0	25·7
130	—	—	—	—	—	—	—	—	—	—	—	—	22·0	22·7	23·5	24·2	24·9	25·5	26·3
140	—	—	—	—	—	—	—	—	—	—	—	—	—	23·2	23·9	24·6	25·4	26·0	26·7
150	—	—	—	—	—	—	—	—	—	—	—	—	—	23·6	24·3	25·0	25·8	26·5	27·2
200	—	—	—	—	—	—	—	—	—	—	—	—	—	—	26·2	27·0	27·7	28·5	29·2
250	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27·6	28·5	29·4	30·1	31·0
300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28·9	29·9	30·7	31·5	32·0
350	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30·0	31·0	32·0	33·0	33·7
400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	31·1	32·0	32·9	33·9	34·7
450	—	—	—	—	—	—	—	—	—	—	—	—	—	—	32·0	33·1	34·0	34·8	35·8
500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	33·8	34·8	35·7	36·7
Deflection in Inches.	·1	·15	·2	·25	·3	·35	·4	·45	·5	·55	·6	·65	·7	·75	·8	8·5	·9	·95	1·0

Table showing the Weight or Pressure a Beam of Cast-iron, 1 Inch in Breadth, will sustain, without destroying its elastic Force, when it is supported at the Ends, and loaded in the Middle of its Length, and also the Deflection in the Middle which that Weight will produce. Calculated by Mr. Tredgold.

Lengths.	1 Foot.		2 Feet.		3 Feet.		4 Feet.		5 Feet.		6 Feet.		7 Feet.		8 Feet.		9 Feet.		10 Feet.		12 Feet.		14 Feet.		16 Feet.		18 Feet.		20 Feet.		22 Feet.		24 Feet.		26 Feet.		28 Feet.		30 Feet.	
Depth.	lbs.*	defl.	lbs	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lb	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.	lbs.	defl.
1 in.	850	·02	425	·08	283	·18	212	·32	170	·5	142	·72	121	·98	106	1·28	95	1·62	85	2·0																				
1½	1912	·014	956	053	637	·12	477	·21	383	·33	320	.48	273	·65	239	·85	214	1·08	192	1·34																				
2	—	—	1700	·04	1132	·09	848	·16	680	·25	568	·36	484	·49	425	·64	380	·81	340	1·0	283	1·44	243	1·96	212	2·56	189	3·24	170	4	154	4·84	142	5·76	131	6·76	121	7·84	113	9·0
2½	—	—	2656	·032	1769	·072	1325	·128	1062	·20	887	·29	756	·39	662	·51	594	·65	531	·8																				
3	—	—	—	—	2547	·06	1908	·11	1530	·167	1278	·24	1089	·33	954	·426	855	·54	765	·66	637	·96	546	1·31	478	1·71	425	2·16	382	2·67	347	3·23	318	3·84	294	4·51	273	5·23	255	6·0
3½	—	—	—	—	3467	·052	2597	·092	2082	·143	1739	·205	1482	·28	1298	·365	1164	·46	1041	·57																				
4	—	—	—	—	—	—	3392	·08	2720	·125	2272	·18	1936	·245	1700	·32	1520	·405	1360	·5	1133	·72	971	·98	849	1·28	755	1·62	680	2·08	618	2·42	566	2·88	523	3·38	485	3·92	453	4·50
4½	—	—	—	—	—	—	4293	·071	3442	·111	2875	·16	2450	·217	2146	·284	1924	·36	1721	·443																				
5	—	—	—	—	—	—	—	—	4250	·1	3560	·144	3050	·196	2650	·256	2375	·32	2125	·4	1771	·58	1518	·78	1328	1·02	1180	1·29	1062	1·6	966	1·93	885	2·30	817	2·70	759	3·14	708	3·6
6	—	—	—	—	—	—	—	—	—	—	5112	·12	4356	·162	3816	·213	3420	·27	3060	·33	2548	·48	2184	·65	1912	·85	1699	1·08	1530	1·34	1360	1·61	1274	1·92	1176	2·25	1092	2·61	1019	3·0
7	—	—	—	—	—	—	—	—	—	—	6958	·103	5929	·14	5194	·183	4655	·23	4165	·29	3471	·41	2975	·58	2603	·73	2314	·93	2082	1·14	1893	1·38	1735	1·65	1602	1·93	1487	2·24	1388	2·57
8	—	—	—	—	—	—	—	—	—	—	9088	·09	7744	·123	6784	·16	6080	·203	5440	·25	4532	·36	3884	·49	3396	·64	3020	·81	2720	1·00	2472	1·21	2264	1·44	2092	1·69	1940	1·96	1812	2·25
9	—	—	—	—	—	—	—	—	—	—	—	—	9801	·109	8586	·142	7695	·18	6885	·22	5733	·32	4914	·44	4302	·57	3825	·72	3438	·89	3123	1·07	2862	1·28	2646	1·50	2457	1·74	2295	2·0
10	—	—	—	—	—	—	—	—	—	—	—	—	12100	·098	10600	·128	9500	·162	8500	·2	7083	·288	6071	·392	5312	·512	4722	·648	4250	·8	3863	·968	3541	1·152	3269	1·352	3035	1·568	2833	1·8
11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12826	·117	11495	·15	10285	·182	8570	·26	7346	·36	6428	·47	5714	·59	5142	·73	4675	·88	4285	1·05	3955	1·23	3673	1·425	3428	1·64
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15264	·107	13680	·135	12240	·17	10192	·24	8736	·33	7648	·43	6796	·54	6120	·67	5560	·81	5096	·96	4704	1·13	4368	1·31	4076	1·5
13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16100	·125	14400	·154	11971	·22	10260	·307	8978	·39	7980	·49	7182	·61	6529	·74	5985	·886	5525	1·04	5130	1·23	4788	1·38
14	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18600	·115	16700	·143	13883	·21	11900	·28	10412	·36	9255	·46	8330	·57	7573	·69	6941	·824	6408	·965	5950	1·12	5553	1·28
15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15937	·19	13660	·26	11952	·34	10624	·43	9562	·533	8692	·645	7967	·75	7355	·9	6829	1·03	6374	1·2
16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18128	·18	15536	245	13584	·32	12080	·403	10880	·5	9888	·63	9056	·72	8368	·84	7760	·98	7248	1·13
17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20500	·17	17500	·23	15353	·3	13647	·38	12282	·47	11166	·567	10235	·673	9447	·79	8773	·92	8188	1·06
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	22932	·16	19656	·217	17208	·284	15700	·36	13752	·442	12492	·54	11448	·64	10584	·75	9828	·87	9180	1·0
19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25404	·152	21800	·207	19053	·27	16935	·34	15242	·42	13857	·51	12702	·607	11725	·71	10887	·825	10161	·95
20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28332	·144	24284	·195	21248	·256	18888	·324	17000	·4	15452	·484	14164	·576	13076	·676	12140	·784	11332	·9
21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	31230	·138	26770	·186	23428	·245	20825	·31	18742	382	17036	·45	15618	·55	14417	·645	13387	·75	12495	·86
22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	34500	·131	29300	·178	25712	·235	22855	·295	20570	·365	18700	·44	17146	·525	15823	·615	14693	·71	13713	·815
23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37600	·127	32000	·17	28103	·225	24980	·282	22482	·35	20439	·42	18735	·5	17286	·59	16059	·68	14988	·78
24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40768	·12	34944	·163	30592	·216	27184	·27	24480	·335	22240	·402	20384	·48	18816	·565	17492	·665	16304	·75
25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	37700	·156	33203	·21	29514	·26	26562	·32	24148	·387	22135	·46	20432	·54	18793	·625	17708	·72
26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40900	·15	35912	·197	31922	·25	28730	·307	26118	·375	23941	·443	22100	·52	20521	·607	19153	·695
27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	44000	·143	38728	·19	34425	·24	30983	·297	28166	·36	25819	·427	23832	·5	21130	·58	20655	·667
28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	47300	·14	41650	·183	37022	·23	33320	·286	30290	·347	27766	·41	25630	·48	23800	·56	21213	·645
29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	44678	·176	39714	·223	35742	·275	32493	·333	29785	·395	27494	·462	25530	·54	23828	·62
30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	47808	170	42498	·216	38250	·266	34767	·322	31869	·384	29421	·450	27315	·522	25497	·60
31	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	51053	·164	45380	·207	40882	·257	37148	·31	34035	·37	31417	·435	29173	·505	27288	·58
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	54400	·16	48371	·202	43520	·25	39563	·302	36266	·36	33477	·42	31086	·49	29013	·56
33	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	51425	·196	46282	·242	42075	·293	38568	·35	35602	·41	33058	·47	30855	·545
34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	54586	·19	49130	·235	44663	·283	40941	·336	37792	·398	35093	·46	32753	·53
35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	57847	·185	52062	·228	47329	·276	43385	·329	40048	·386	37187	·448	34708	·514
36	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	61200	·18	55080	·222	50073	·269	45900	·32	42369	·375	39343	·435	36720	·5

* The first column shows weight in pounds: the second the deflection in inches.

The direct cohesion of cast-iron has been variously estimated: Captain Brown found that a bar $1\frac{1}{4}$ inch square broke with a force of 11·35 tons, and estimated its cohesion at 7·26 per square inch. Mr. George Rennie found it to be 8·104 and 8·14 tons, when he made his experiments upon a bar only $\frac{1}{4}$ of an inch square.

A bar of malleable iron admits of considerable torsion without having its strength much diminished, but cast-iron fractures easily when submitted to twisting.

The cohesive power of cast-iron has by some writers been estimated at 10 tons per square inch of section; by others at 18,000 or 19,000 pounds avoirdupois, one-third of which may be taken as the permanent cohesive strength for practical purposes. Mr. George Rennie has given us some experiments, which he made upon the resistance of $\frac{1}{4}$ inch iron bars, when subjected to a wrenching force; he made use of a wrought-iron lever, 2 feet in length, having an arched head of about 60 degrees, and 4 feet in diameter, of which the lever represented the radius; in the centre round which it moved was a square hole that received the iron bar to be twisted: the lever was balanced, and a scale hung on the arched head, the other end of the bar being fixed in a square hole in a piece of iron, and that again in a strong vice; it was found that $\frac{1}{4}$ inch bars cast horizontal twisted when 9 lbs. 15 ounces were placed in the scale, and that 10 lbs. 10 ounces were required to those bars which were cast in a vertical position, to produce the same effect.

Numerous experiments have been made upon the vertical strength of iron wires of different diameters, but there is a great discrepancy among them; in those from $\frac{6}{10}$ to $\frac{1}{10}$ of an inch in diameter, their strength per square inch has been estimated at from 30 to 40 tons; the mean strength of iron wire, which does not exceed the length of an inch in diameter, will not support more than 36 tons load.

The cohesive strength of wrought-iron being from 55,000 pounds per square inch to 70,000; when it is required to find its ultimate cohesive strength, the area of its section must be multiplied by the relative cohesive strength, or rather by one-third of what it is supposed to be, when applied to practical purposes.

As the transverse strength of wrought or malleable inch-round iron bars, 12 inches long, loaded in the middle, and lying loose at the ends is equal to 3152 lbs. avoirdupois, and for an inch square bar 4013 lbs., to find their ultimate strength, it is only necessary to multiply this strength of the square bar by the breadth, and the square of the depth in inches, and divide the product by the length in feet; the quotient will be the weight in pounds avoirdupois.

When malleable iron is subjected to the force of *tension*, its absolute resistance has been found to vary from 50,000 pounds to 80,000 pounds per square inch of section according to its quality, and its strength to resist torsion 15,360 lbs.: this is directly as the cube of one side, and inversely as the force applied, multiplied into the length of the lever; for if we multiply the strength of an inch-iron bar by the cube of one side in inches, and divide the product by the length of the lever in inches, the quotient will give the ultimate strength of the bar in pounds avoirdupois, or if the bar is round, the cube of its diameter must be divided by the length of the lever: or the diameter or side of a square bar may be found by multiplying the force applied in pounds by the length of the lever in inches, dividing the product by one-third of the ultimate strength of an inch bar, when the cube root of the quotient will be the diameter or side of the square in inches, capable of resisting permanently that force.

In revolving shafts for machinery, the strength is directly as the cube of their diameters and revolutions, and inversely as the resistance they have to overcome. A forty-horse-power steam-engine making 25 revolutions a minute is found to require a wrought-iron shaft 8 inches in diameter; the cube 8 multiplied by 25, and divided by 40, is equal to 320, a constant number or multiplier for all others; as for example, an engine 65 horse power making 23 revolutions per minute,

$$\sqrt[3]{\frac{65 \times 320}{23}} = 9{\cdot}67 \text{ inches diameter nearly.}$$

200 is the constant multiplier or number made use of in general for all second movers, and 100, for that of shafts connecting the smaller parts of machinery.

Corrugated Iron is employed in the covering of buildings, and it was first used at the Eastern Counties Railway shed at the London terminus, built in 1840. The plan is a rectangle, being 230 feet in length, and the width is divided into three spaces; that in the middle is 36 feet in width, and those on each side 20 feet 6 inches: the rows of cast-iron columns seventeen in each, and distant 13 feet 6 inches from one another; over their capitals they are connected by a cast-iron elliptical girder $\frac{3}{4}$ of an inch in thickness with open panels; over this is a cast-iron gutter. The centre roof rises 9 feet, and that of the side roofs 4 feet, the springing line above the rails being 22 feet 6 inches.

The corrugated wrought-iron is of the sheets called No. 16 wire gauge, or in thickness the fourteenth of an inch; and the arch is formed by curving the sheets of iron in the transverse direction to the arches themselves, and riveting them together in the direction of their length.

The superficial content of the middle span is 10,235 feet, and that of the two side roofs 10,810 feet, each being a little more than half that in the centre. As the weight of this corrugated iron is 3 pounds per superficial foot, the whole weight is 28¼ tons: the cost of erection was 6*l.* 10s. per square of 100 feet, or 1365*l.*

The water is carried off from the roof down the curves of corrugation, first into the gutter, then through the hollow columns, and afterwards by drains. A single sheet of this iron was found to bear 700 pounds weight in a vertical position without bending. Many other roofs of this description have been executed, and apparently stand well; one at the London docks is 225 feet in length, and 40 feet span. St. Catherine's Docks, the Birmingham, Blackwall, and numerous other railways, have made use of them.

Galvanised iron, as it has been termed in France, is made by covering the metal with a coat of tin by a peculiar process, and for a time it resists the corrosive effects of the atmosphere as well as that of water: the surface of the iron is first rendered perfectly clean by the joint action of dilute acid and friction; after which, it is plunged into a bath of melted zinc, and moved about until entirely covered with the alloy; it is then taken out and immersed in a bath of tin, which covers it with a thin coat of alloy. It is stated that when iron thus heated is exposed to humidity, the zinc slowly oxidises, and protects the former from rusting within it whilst the outer tinned surface remains.

Coal is found in many parts of the British Islands. The culmiferous series in Devonshire lies in a great basin, the axis of which extends 50 miles from east to west, with an average breadth of 30 miles; the upper beds of slate of the Devonian system are occupied by dark coloured limestone, over which occurs a stratum of siliceous flagstones; over these are sandstones, carbonaceous and calcareous slates, which are surmounted by a bed of thick sandstone.

The South Wales coal field extends about 90 miles along the shores of the Bristol Channel; its greatest breadth is not more than 20 miles; the number of bands of coal is considerable; their thickness varies from 18 inches to 9 feet, and the whole taken together amount to a depth of 95 feet: in the deepest part they lie about 13,000 feet below the surface.

The Somersetshire and Bristol coal field is of small extent; that of South Staffordshire has only eleven seams, but the main bed in the middle is upwards of 30 feet in thickness; this seam crops out near Bilston. The coal in the northern portion contains numerous impressions of plants.

The Shrewsbury coal field is not very extensive: that in Flintshire is under the new red sandstone; this latter is about 40 miles in length, and 3 in breadth. But the most important of all are those in the north of England, which form three districts: in the first is comprised Yorkshire, Derbyshire, and Nottinghamshire; in the second, Lancashire; and in the third, Durham and Newcastle.

In the first the beds vary from 2 to 5 feet in thickness, and are of a bituminous quality. In the Lancashire district, the extent from north to south is 46 miles, and about 40 in width: in some parts there are 75 seams, forming altogether 150 feet of workable coal.

Coal Fields.—The chief in England is the Newcastle, and lies between the rivers Coquet and Tees, its length being nearly 50 miles, and its breadth upwards of 20; the area of this district, so important to British trade and manufactures, is computed at 800 square miles. It is divided by a great fault, which crosses it north of the Tyne, where the strata are thrown downwards on the one side, and uplifted to a height of 90 fathoms on the other; this fault is termed the main dyke. The most valuable working is the high main, where the coal is 6 feet in thickness.

Boring is first resorted to for the purpose of ascertaining the best position for sinking the shaft by which the coal is to be drawn up; this is performed in the ordinary way by means of successive iron rods and machinery to work them, the cost of which is 12 shillings per fathom for the first ten, and an additional 6 shillings for each 5 fathoms beyond.

The shafts are cylindrical, and seldom less than 10 feet in diameter; these are divided by a wall; some of the larger shafts are formed into three compartments, one of which is used for ventilation, another for drainage, and the third for drawing up the coal. Great expense and caution are necessary in the works appertaining to this part of the operation; the whole of the shafts require to be cased or lined with good bricks or stone, and where the springs are abundant there must be a tubing or a crib formed of whole deals attached to circular ribs or curbs; metal castings are now sometimes substituted, as better calculated to resist the extraordinary pressure to which the curb is subjected.

These shafts commonly extend to the depth of 150 feet, and sometimes as much as 1800; that at the Wearmouth Colliery, near Sunderland, passes through the capping of magnesian limestone, the lower beds of which, with the lower new red sandstone, overlap the coal measures. After the shaft had been sunk 330 feet, the workmen tapped a spring, which poured out 3,000 gallons of water per minute; this, however, being subdued by the working of a steam-engine of 200 horse-power, a strong metal cylinder was introduced, and carefully placed around the shaft; the sinking was then continued to the depth of 1578

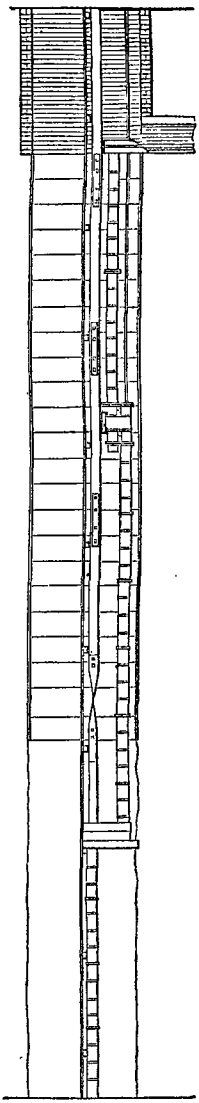
feet, when a very valuable seam of coal was arrived at; during the ten years employed in sinking this pit upwards of 100,000*l.* were expended.

In Staffordshire the coal is drawn out by means of a number of pits, which are not required to be of great depth. When the shaft is first sunk, two galleries are driven, one in an horizontal line along the strike of the coal seam, the other on the rise of the bed, at right angles to it. The first is termed the drift or watercourse, and the other the winning headway, through which the coal is brought to the shaft to be hauled up: these cuttings are 9 or 10 feet in width, 6 feet in height, and are made convenient for the passage of the waggons, which in some cases run upon rail or tramroads. After the drift and winning headway are completed, other galleries, varying in dimension, are set out parallel to the latter; some are 9 or 10 feet in width, intersected by others at right angles, the pillars of coal which are left between the galleries for the purpose of support being generally 8 or 9 yards in thickness; and in the old method of mining these pillars were left, but since panel work was introduced, fifty years ago, they have been extracted: this is performed by dividing the entire mine into panels, separated by walls of coal from 40 to 50 yards in thickness, and then extracting the coal from each in succession, commencing work in that most distant from the shaft, shutting off all communication with the others till the whole panel is worked out. Pillars about 24 yards by 12 are at first left between the boards, as the largest galleries are called, and the transverse galleries or rooms, and when the first are completed the miners attack the pillars; the roof being supported by posts of Scotch fir, which are removed as the work proceeds, and the roof is then suffered to fall in. Thus the whole of the coal is now removed, and by allowing the galleries to be filled up, all danger from an accumulation of the noxious gases is prevented.

The tools used by the collier are a mattock having both ends of the head pointed, and several kinds of chisels, crow-bars, and hammers. The coal is generally blasted, and then broken up into small masses; the blasting is effected by piercing the lower part of the seam with a hole about 1 inch in diameter and 3 feet in depth, into which the cartridges are introduced, and the hole is plugged up with coal dust; the men who obtain the coal are called hewers, and those who load the waggons or corves the putters, who also conduct the horses to the bottom of the shaft, where the coal is drawn up.

In the Dudley coal field, where the thickness of the seam is as much as 30 or 40 feet, it is worked in chambers, which are called sides of work.

The strata of coal in England usually lie horizontal; in Wales and in Scotland they are inclined, sometimes at a considerable angle; where this is found to be from 45° to 60°, as in Pembrokeshire, the mine is worked by an adit level, which passes out on a hill side. Windlasses placed along the inclined vein draw up the coal after it has been extracted from the stalls; two sets of carts are used for the purpose, so attached to the windlasses that those which are full draw up the empty.



COAL MINE SHAFT.

Fig. 592.

The whim for raising coals from the shaft is now generally worked by a steam-engine, which gives motion to a hollow drum on which the rope winds that brings up the materials.

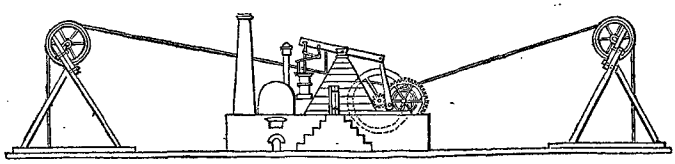


Fig. 593. WHIM FOR RAISING COAL.

The ventilation of coal mines is effected by means of rarefaction; a furnace is placed at the bottom of the pit, which produces a rapid ascending column of warm air, and as this rises up the shaft its place is supplied by a current of cold air, which passes down one of the other compartments of the shaft, and is made to traverse the several workings of the mine before it is permitted to arrive at the furnace, where in its turn it becomes rarefied. In the Wallsend colliery the quantity of fresh air thus admitted varies from 2000 to 3000 cubic feet per minute; in some of the coal mines the air has so many miles of gallery to traverse that it is 12 hours before it arrives at the furnace, the rate at which it progresses being about 2 feet per second or a little more. The wall of separation in the shaft is called the brattice, and is of two kinds: one is permanent, and usually 2 or 3 feet in thickness; the other is of a more temporary kind, composed of 3-inch deals, so attached to a skeleton frame that it can be easily removed. Where the galleries are shut off, to prevent the current of air from passing, the wall is called a stopping; this is sometimes effected by trap-doors, made either single, double, or triple, as may be most convenient; the air course is called either the intake or return as it receives or emits the air.

Lighting Coal Mines.—The means of effecting this, without subjecting the workmen to the dreadful calamities arising from the explosive nature of the gas when mixed with atmospheric air, had long occupied the anxious attention of scientific men, but without success, until the experiments of Sir Humphry Davy happily led him to construct a lamp by which the lives of incalculable numbers have been preserved. He found that no mixture of fire-damp would explode in tubes with a diameter of less than $\frac{1}{8}$ of an inch; and also that a much stronger heat was required to effect this than with mixtures of common inflammable gas, and that neither charcoal nor iron made red-hot would produce an explosion. Upon these principles Sir Humphry formed the lamp called after him: the flame is enclosed within a wire gauze of very small meshes, there being as many as 784 to the square inch; the security which it affords to those for whose use it was invented is not, however, sufficiently estimated, in consequence of its not affording a great abundance of light, and in many instances there has been much difficulty in enforcing its introduction. Besides the fire-damp there is another noxious gas, called the choke or black damp; this is a carbonic acid, and from its density will not rise to the surface, but sinks to the bottom of the mine. The heavy carburetted hydrogen is also found; this, when mixed with certain proportions of common air, is exploded by either charcoal or iron heated to a dull red heat.

The Scotch Coal Fields are about 100 miles in length, and 30 in breadth; and the number of beds are said to be 337, 84 of which are coal; the total thickness of all these layers is computed at not less than 5000 feet.

The Coal Fields in Ireland are nearly 150 miles in length, and 120 in breadth, covering a surface of more than 10,000 square miles. The coal is anthracitic, being often found in the state of pure anthracite.

The first charter for the licence of digging coal was granted by Henry III., in the year 1239, and it is there called sea-coal; it became a common fuel soon afterwards, and a considerable quantity appears to have been exported to France. When Mr. Taylor, a few years ago, gave his evidence on the coal mines before the Committee of the House of Lords, he stated that the annual consumption of coal in Great Britain amounted to 19,540,000 tons.

Coking of Pit Coal.—The most common method is to throw up the coals in heaps of about 40 tons as loosely as possible, and cover them with the smaller pieces; fire is then applied at various parts, and the mass is suffered to burn until the whole is ignited; when this is effected, it is covered up with dust and ashes to exclude the air, and the heap is suffered gradually to cool: water is often poured over it to accelerate this last part of the process, which is said to improve the quality of the coke by making it harder.

Ovens are used for making the better quality of coke; the best are usually elliptical in their form, about 12 feet in their longest diameter, and 11 feet in the other; the walls are 3 feet in thickness; the mouth is usually lessened towards the inside to about 2 feet 6 inches, that on the outer side being a foot more. At the back is the entrance into the flue which conducts to the chimney; this is regulated by means of fire bricks, which can be moved to increase or diminish the draught, so as entirely to consume the smoke.

A series of eighteen ovens, with a flue at the back 1 foot 9 inches wide, and 2 feet 6 inches high, have been constructed at the station of the Birmingham railway; and the flues are conducted into a chimney 11 feet clear diameter at bottom, 17 feet outside, and 115 feet in height. These ovens are each charged with $3\frac{1}{2}$ tons of good coal, and entirely consume the smoke from the moment they are first lighted up; in about 40 hours it is sufficiently coked, when it is thrown out upon the ground and watered; it is then put into iron canisters and covered up: good coal will yield 80 per cent. of coke, weighing 14 cwt. per chaldron. The loss of weight when coals are coked in the ordinary manner is about 25 per cent., and coal which thus loses $\frac{1}{4}$ in weight gains $\frac{1}{4}$ in bulk.

CHAP. III.

ON STONE.

GREAT attention has been deservedly paid to the quality of the materials made use of in building, and the knowledge on the subject has been greatly advanced by the mineralogist and chemist. Vitruvius asserted that all bodies consist and spring from earth, air, fire, and water, but has not given us the quantity of each that enters into their composition: these original elements, he observes, are not only indivisible, but also incapable of change or of destruction; this is not exactly the case, for we find that stone is acted upon chemically as well as mechanically, and that it exhibits, when applied to buildings, the same decomposition to which it is subject when attached to its native rocks. Stone is variously acted upon in different situations: in cities, when exposed to the influence of the smoke of coal, some varieties are rapidly decomposed; other kinds are affected by the alternations of dryness and humidity; particular streams rapidly destroy some limestones, and materially injure the granites.

The limestones used by the Egyptians, Greeks, and Romans, have endured to this day: the sandstones employed in their temples and public edifices in many situations exhibit no decomposition, and the granite of all varieties remains perfectly entire; showing that the architects of antiquity knew how to select their material, and to apply it in such a manner that it was not subjected to any greater action by exposure than it had to encounter in its natural bed.

Stone Quarries. — The stone found near the surface, and which has been exposed to the action of the atmosphere, is not so sound as that which is taken from a depth, where it has been subjected to great pressure, and the greater the depth, generally speaking, the greater is its hardness and density. On opening a quarry, the first consideration is the means of raising and delivering the stone in the least expensive manner; an excavation is usually made in the side of a hill, in preference to *uncallowing* the top, in order that the road leading from it should have as gentle an inclination as possible; for if the quarry be sunk very low, the difficulty and expense of drawing out the blocks of stone are seriously increased.

The stone is generally found in beds or masses, divided by joints, at which divisions the natural adhesion is broken, and there is no difficulty in detaching the blocks, nor risk of breaking them: where vertical pressures exist, which is often the case, their removal is facilitated; but it is sometimes necessary to break the contiguous blocks, or blast them with gunpowder. Wedges of steel, driven in by a heavy sledge hammer, are often used to separate the stone from its bed: in order that the edges may not be broken, or rendered ragged by removal, they are elevated to the platform or truck by an instrument called the *lewis*, which consists of three pieces of strong iron, formed and held together by a shackle and screw bolt; two sides are parallel to each other, or the pieces are of the same thickness throughout, which varies from 1½ to 3 inches, according to the weight it is destined to carry. The two pieces outside spread out, and at the bottom are twice the thickness that they are above; the middle piece is of the same size at top and bottom, consequently when the three pieces are put together, the width at the bottom is one third more than at the top; by taking out the screw-pin, and withdrawing the central piece, the two others are brought together, and introduced into a sunk groove in the stone, cut like a dovetail, or spreading at the bottom, of a sufficient dimension to take in the whole lewis, which is placed in separate pieces, the middle being the last; the bolt and shackle are then attached, and the lewis now occupying the whole cavity, no force can detach it; by this means enormous masses are lifted perpendicularly by blocks and falls, worked by a piece of machinery called a crab. The upper block, which sustains the weight, is attached to a crane or strong beam of timber, fixed as perpendicularly as possible, with its block over the stone, every precaution being taken to prevent its lower extremity from slipping. The crab is so placed as to have the draught of the rope as nearly as possible in the direction of the pole, the top of which is either secured or moved by guy ropes, worked also by blocks and falls fastened to the ground; where the weights are great, two poles are sometimes used for more security.

When the stone in the quarry does not exhibit any natural joints or fissures, but apparently forms one compact mass, a line of holes is drilled at short and regular distances, into which are put conical steel pins, rather larger than the holes, which, being struck simultaneously by the hammers of the miners, produce a separation in the direction desired. Wooden pegs are occasionally substituted, where the cleavage is easy, around which a clay wall is built, filled with water; in a short time the pegs swell and separate the stone.

To drill the holes in very hard stone, it is necessary to have a steel cold chisel about 2 feet long, and the breadth of the hole required, the edge being double bevelled, and not too sharp; a workman holds this instrument where the hole is to be made, whilst another strikes it, taking care that the drill is turned partly round, or kept revolving during the succession of blows; as the indentations are made, the powdered stone or dust is removed from the hole. When rocks are blasted by gunpowder, the holes are drilled to a greater depth, usually 16 or 18 inches deep, and an inch or more in diameter; the powder is introduced into them, sewed up in a linen bag, with a cartridge made of tin; dry sand is put upon it and rammed down, and the top of the hole is filled with moistened sand. A train of powder in a fine tin tube is connected with the holes, to which is attached a slow match or some wild-fire, so arranged as, when fired, to give the workmen time to retire out of all danger from the scattering of the fragments, which occasionally is attended with great violence. Voltaic electricity, conducted by means of wires, has been effectually applied to the ignition of the gunpowder, which is attended with infinitely less casualties, inasmuch as if ignition does not immediately take place, it is not to be feared afterwards.

In the selection of stone for the purposes of construction, regard must not only be had to the colour and texture, but also to its power of withstanding the exposure to atmospheric agency, or the decomposing effects of water. Stones are composed of various earthy substances in such a state of hardness as not to be softened by immersion in water under ordinary circumstances; they may be classed under three distinct divisions, viz. the sandstones, limestones, and granites.

Sandstones are formed of angular or rounded grains of different earths or minerals, which are either held together by a cement or base, or joined without any such basis by simple juxta-position: when the grains composing them are small, they are called sandstone, but when they increase in dimension, they are designated conglomerate, if the particles are rounded; if angular, they take the name of brescia. The consolidation of the various sandstones seems to have taken place not during the time they were forming under water, but when they were upheaved, or had the water drawn from them; this is implied from the fact that most sandstones, when first taken from the quarry, are softer than after exposure to the air; no doubt the water which they contain is speedily evaporated, and the minerals it holds in solution become deposited, and by their crystallisation give greater hardness and consistency to the mass, binding it more firmly together, and rendering it more difficult to cut; some varieties are so plastic, when first taken from the quarry, that they may be easily compressed, and afterwards, from the loss of the water they contain, become perfectly hard. Sandstones are divided into three varieties, according as the quartz or siliceous grains composing them are cemented by siliceous, argillaceous, or calcareous matter.

In the siliceous kinds the particles are cemented by a base of quartz: in the argillaceous by a base of clay, usually impregnated with a red oxide of iron, which gives that tint to the whole rock; and in the calcareous kinds by a marly or calcareous cement, and it must be obvious that the quality of sandstone entirely depends upon the durability of its cementing properties. As the particles which are held together, being silex in nearly a pure state, are not acted upon by either air or water, its decomposition is found to commence by the destruction of its base, which liberates the grains in the sandstone, or permits them to crumble into fine sand: when the base is highly impregnated with silica, it is very hard, has almost the character of porphyry, and seems to defy decomposition.

In the varieties of sandstone with small grains, set in an argillaceous or calcareous base, the colours vary from red, grey, green, yellow, and brown, and are arranged in zones or bands dependent upon the oxidation of the iron in the base or cement. This variety of sandstone is found alternating with beds of red-coloured clay, or marl, which is sometimes slaty, or mixed with sand and mica, passing into sandstone slate; the beds are of great thickness.

From sandstone being formed in strata, and laminated, it is obvious that when applied to building purposes, they should be so placed as to correspond with their natural beds, for if in any other position, or vertical to their planes of stratification, any weight placed upon them would tend to cleave or split them into laminæ.

The sandstones that have undergone an analysis consist of: —

	Craglelth.	Darley Dale.	Heddon.	Kenton.	Mansfield.
Silica	98·3	98·40	95·1	93·1	49·4
Carbonate of lime	1·1	0·36	0·8	2·0	26·5
——— magnesia	0·0	0·0	0·0	0·0	16·1
Iron alumina	0·6	1·30	2·3	4·4	3·2
Water and loss	0·0	1·94	1·8	0·5	4·8
Bitumen	0·0	0·0	0·0	0·0	0·0
Specific gravity of dry masses	2·232	2·628	2·229	2·247	2·338

	Cragleith.	Darley Dale.	Heddon.	Kenton.	Mansfield.
Specific gravity of particles	2·646	2·993	2·643	2·625	2·756
Absorbent powers, when saturated under the exhausted receiver of an air-pump	0·143	- -	0·156	0·143	0·151
Disintegration—Quantity of matter disintegrated	0·6 grs.	0·121 grs.	10·1 grs.	7·9 grs.	7·1 grs.
Cohesive powers	111	100	56	70	72

As a general remark it may be inferred that those stones which have the greatest specific gravity possess the greatest cohesive strength, absorb the least quantity of water, and disintegrate the least by the process which imitates the effects of weather, though we are not able to compare stones of different classes together, for while sandstones absorb the least water, they disintegrate more than the magnesian limestone, which absorbs a great quantity of water.

Names of the Quarries specified.	Weight in ordinary Slate in, Grains.	Weight when well dried in Grains.	Weight when saturated with Water in Grains.	Weight of Water absorbed in Grains.	Bulk of Water absorbed; 2-inch Cubes considered as Unity.	Weight of Particles disintegrated in Grains.	Cohesive Powers. Weight producing First Pressure.	Cohesive Powers. Crushing Weight.	Specific Gravity of the dry Specimens.	Specific Gravity of the Solid Particles.	Bulk of Water absorbed; total Bulk considered as Unity.
Cragleith -	4698·7	4695·6	4859·0	163·4	0·080	0·6	60	111			
Ditto -	4737·8	4734·3									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·266	2·646	0·143
Darley Dale	4685·2	4678·3	4826·5	148·2	- -	- -	88	100			
Ditto -	4746·2	4737·4	4880·0								
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·230	2·666	0·163
Heddon -	4557·1	4553·8	4765·10	211·2	0·104	10·1	26	56			
Ditto -	4594·0	4588·3									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·229	2·565	0·156
Kenton -	4658·4	4647·9	4848·5	200·6	0·099	7·9	48	70			
Ditto -	4595·4	4581·5									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·045	2·706	0·244
Mansfield -	4700·2	4695·3	4906·0	210·7	0·104	7·1	28	72			
Ditto -	4733·5	4719·4									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·338	2·756	0·151
	Results of experiments upon cubes of 2 inches in diameter.								Results of experiments on cubes of 1 inch in diameter.		

In the foregoing table the first column gives the name of the quarry where the specimen was procured.

The second indicates the weights of the specimens in the state in which they are usually employed for the purposes of building, subjected only to the atmospheric influences since taken from their respective quarries and worked.

The third contains the weights of the same specimens, after having been perfectly dried, by exposure in heated air for several days: their relative specific gravities are indicated by these numbers, subject to the errors arising from differences in the sizes of the cubes, which, on account of the accuracy of the measurements, varied but little from each other; the specific gravities, however, taken by the most certain method, will be found in columns 10 and 12.

The fourth exhibits the weight of one set of the above-mentioned cubes, after having been immersed in water for several days, so as to become completely saturated, such weights having been ascertained immediately after the cubes were taken out of the water, and wiped.

The fifth shows the difference of weight between the same specimen in its dried and in its saturated state, and indicates, therefore, the quantity (by weight) of water absorbed by each stone.

The sixth shows the relative bulk of water absorbed, 8 cubic inches, or the bulk of the cube being taken as unity.

The seventh gives the quantity of disintegration of the several stones in grains, after having been simultaneously subjected to Brard's process for eight successive days; the measures thus obtained may be considered very closely to represent the action of the atmosphere during successive winters on the various stones submitted to examination.

The eighth and ninth columns contain the results relating to the cohesive strength of the stones, or their resistance to pressure. These experiments were made at the manufactory of Messrs. Bramah and Robinson with a 6-inch hydrostatic press, the pump of which was 1 inch in diameter: according to previous trials by Messrs. Bramah and Robinson, 1-pound weight at the end of the pump lever produced a pressure on the face of the cube equal to

2·53 cwt., or 71·06 lbs. on the square inch. The experiments with the stones were cautiously made; the weight on the lever was successively increased by a single pound, and in order to ensure greater accuracy, a minute was allowed to elapse previous to the application of each additional weight. The *eighth column* shows the pressure at which the stone commenced to crack, and the *ninth* the pressure at which it was crushed. The unit assumed is the pound weight placed at the end of the lever; the employment of this unity in the table is preferred to stating the calculated weights, because it is not wished to give a greater appearance of accuracy than can strictly be adjudged to the experiments; but if absolute measures be required, the pressure either upon the face of the cubes employed on 1 square inch of the surface may be estimated, as nearly as the means employed enabled it to be ascertained, by multiplying the figures in the table by either of the values of the unit above stated. The results having been obtained with the same press, and under the same circumstances, it is presumed that no objection can be made to them as comparative experiments.

The tenth indicates the specific gravities of the stones, accurately taken by the means usually employed.

The eleventh contains the specific gravities of the solid materials of which each stone is composed, on the supposition that the water absorbed, when the atmospheric pressure is removed, completely replaces the air which before occupied the pores.

The twelfth shows the bulk of water absorbed by the stones when saturated under the exhausted receiver of an air-pump, their entire bulk being taken as unity. The quantity of water absorbed in this process may be considered to represent space occupied by the pores or interstices in the substance, unless we suppose that in some cases the adhesion between air and the solid particles is so great that the entire removal of the atmospheric pressure is not sufficient to counteract the force. It is certain when this pressure is not removed, long immersion in water will not occasion the displacement of all the air contained within its pores.

Sandstones on the continent, as well as in England, are less used in architecture than calcareous stones; there are nevertheless some kinds which are sufficiently solid, and may be safely employed in those districts where calcareous stones are wanting. At Paris the sandstones found in the environs are only used for paving, in consequence of the difficulty with which they are worked: many of the sandstones, which appear to be very friable, and readily affected by the air, are used with advantage in constructions under water.

Limestones, or *Calcareous Stones*, are the most generally used in the construction of edifices, and are called calcareous, because, when exposed to heat, they are reducible to lime; they are also distinguishable by being soluble in acids, in which they strongly effervesce: a drop of nitric acid falling on a calcareous stone, it bubbles and hisses, like hot iron plunged into water; when struck with the steel it emits no sparks.

Limestones are most frequently used, not only because most abundant, but also because more easily worked than all others, and possessing sufficient tenacity to resist pressure, and preserve the mouldings, arrises, &c. The varieties are not, however, indifferently used; some have not sufficient cohesive power, as, for example, chalk, several granular calcareous stones, simple or micaceous, from the primitive and intermediate strata, which do not resist pressure; others, having their parts sufficiently compact, are too fragile, or, according to the opinions of the workmen, *too dry*, such as those which are very compact and formed of fine grains having a conchoidal or shelly fracture; these varieties are frequently filled with fissures injurious to their solidity, whether open or filled with calcareous spar. Calcareous stones, most suitable for construction, are the compact, with unequal fracture, flat, or irregular, of an earthy tinge, and these formed of shells, united by a cement, partly earthy, partly crystalline. These varieties abound in the secondary and tertiary formations, in deposits analogous to those of the Jura, and similar to those in the environs of Paris; of these the greater number of the monuments of the civilised world have been constructed; the finest houses of Amsterdam and the mosques of Constantinople are built of this material.

The stones of the secondary formation are also in general use; those in the second bed of tertiary formation are abundantly employed in Paris. The workmen class this under several varieties according to their application.

The calcareous tufa or travertine used in Italy is whitish or yellowish, and is found in the substructions of most of the ancient temples, in the Coliseum and other public buildings in Rome: it must always be placed in the same position as in their natural beds, where it is deposited in horizontal layers; when laid improperly these exfoliate and split vertically; stone of a very compact and homogeneous structure, and forming beds of great thickness, will alone allow of their natural position being reversed.

Calcareous spar is found in crystalline masses, or in colourless crystals; it is easily dissolved by muriatic acid; its specific gravity is 2·7; it loses 46 per cent. by the expulsion of carbonic acid. The *stalactitic* carbonate of lime, or concretionary limestone, is formed of zones which have a fibrous structure arising from the successive deposits of the crystalline limestone from its solvent water. The stalagmite or alabaster limestone does not exhibit concentric zones, but spreads out in a waving and parallel direction. The stalactites are

are formed from the roofs of caverns in the limestone rocks, where the water percolates through them, which is charged with carbonate of lime held in suspension by an excess of carbonic acid, which is precipitated by exposure to air.

Limestones are comprised under three denominations, the simple, the oolite, and the magnesian; these are the varieties usually employed in construction: the most crystalline are the most durable; some contain a quantity of silica; on many the atmosphere has a powerfully decomposing effect; water being first absorbed acts mechanically on the external faces of the stone, occasioning afterwards, by chemical action, an entire change in the constituent parts.

Of the various limestones examined by the Commissioners appointed by the Government previously to the erection of the Houses of Parliament, their composition is as follows: —

	Barnack.	Chilmark.	Hum Hill.
Silica	0·0	10·4	4·7
Carbonate of lime	93·4	79·0	79·3
——— of magnesia	3·8	3·7	5·2
Iron alumina	1·3	2·0	8·3
Water and loss	1·5	4·2	2·5
Bitumen	a trace	a trace	a trace
Specific gravities of dry masses	2·090	2·481	2·260
——— of particles	2·627	2·621	2·695
Absorbent powers, when saturated under the exhausted receiver of an air-pump	0·204	0·053	0·147
Disintegration — quantity of matter disintegrated	16·6 grs.	9·8 grs.	9·5 grs.
Cohesive powers	25·	101·	57·

Name of the Quarry from whence Specimens were procured.	Weight in ordinary State in Grains.	Weight when well-dried in Grains.	Weight when saturated with Water in Grains.	Weight of Water absorbed in Grains.	Bulk of Water absorbed, 2 Cube Inches considered as Unity.	Weight of Particles disintegrated in Grains.	Cohesive Powers. Weight producing First Fracture.	Cohesive Powers. Crushing Weight.	Specific Gravity of the dry Specimens.	Specific Gravity of the Solid Particles.	Bulk of Water absorbed; the Solid considered as Unity.
Barnack	4443·9	4442·3	4729·4	287·1	0·141	16·6	16	25			
Ditto	4235·4	4233·5									
Ditto	- -	- -	- -	- -	- -	- -	- -	- -	2·182	2·687	0·180
Chilmark	4907·1	4897·0	5072·4	174·4	0·086	5·6	36	90			
Ditto	4935·9	4925·3									
Ditto	- -	- -	- -	- -	- -	- -	- -	- -	2·366	2·658	0·109
Ham Hill	4700·3	4695·5	4930·0	234·5	0·115	9·5	22	57			
Ditto	4685·3	4683·5									
Ditto	- -	- -	- -	- -	- -	- -	- -	- -	2·260	2·695	0·147
	Results of experiments upon cubes of 2 inches sides in duplicates.								Results of experiments upon cubes of 1-inch sides.		

Oolite. — This is composed of oviform bodies cemented by calcareous matter of various coherency, and is liable to decomposition as the cementing qualities are chemically or mechanically acted upon: that of Bath and Portland is extensively employed in building; it is worked with great ease, and has a good colour, which it, however, loses when long exposed to the action of the atmosphere; the same cause renders it unfit for fine carving, the delicate portions and arrises soon crumbling away.

The oolites examined by the Commissioners are the following: —

	Ancaster.	Bath Box.	Portland.	Kelton.
Silica	0·0	0·0	1 20	2·0
Carbonate of lime	93·59	94·52	95·16	92·17
——— of magnesia	2·90	2·50	1·20	4·10
Iron alumina	0·80	1·20	0·50	0·90
Water and loss	2·71	1·78	1·94	2·83
Bitumen	a trace	a trace	a trace	a trace
Specific gravities of dry masses	2·182	1·839	2·145	2·045
——— of particles	2·687	2·675	2·702	2·706
Absorbent powers when saturated under the exhausted receiver of an air-pump	0·180	0·312	0·206	0·244
Disintegration — quantity of matter disintegrated	7·1	10·	2·7	3·3
Cohesive powers	33·	21·	30·	36·

Names of Quarries from whence Specimens are procured.	Weight in ordinary State.	Weight when well-dried in Grains.	Weight when saturated with Water in Grains.	Weight of Water absorbed in Grains.	Bulk of Water absorbed; 2 Cube Inches considered as Unity.	Weight of Particles disintegrated in Grains.	Cohesive Powers. Weight producing First Fracture.	Cohesive Powers. Crushing Weight.	Specific Gravity of the dry Specimens.	Specific Gravity of the Particles.	Bulk of Water absorbed; total Bulk considered as Unity.
Ancaster -	4585·4	4584·0	4920·3	336·3	0·166	7·2	24	33			
Ditto -	4543·1	4512·0									
Ditto -	- -	- -	- -	- -	- -	- -	- -	-	2·182	2·687	0·180
Bath Box -	3767·8	3766·8	4109·0	342·4	0·169	20·0	18	21			
Ditto	3876·3	3875·5									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	1·839	2·675	0·312
Portland -	4302·9	4300·4	4375·1	275·1	0·135	2·7	30	55			
Ditto -	4306·9	4305·0									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·145	2·702	0·206
Ketton -	4412·8	4409·7	4715·6	305·9	0·151	3·3	22	36			
Ditto -	4313·2	4309·5									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·045	2·706	0·244
Results of experiments upon cubes of 2-inch sides in duplicate.									Results of experiments upon cubes of 1-inch sides.		

Magnesian Limestone or Dolomite, when of a crystalline character, and with nearly equivalent proportions of carbonate of lime and carbonate of magnesia, is preferred to most others, on account of the uniformity of its texture, and the facility with which it is worked. Like common limestone it can be formed into mortar, though it remains much longer caustic than quicklime made from the latter; this constitutes the important difference between magnesian and common limestones when employed in agriculture; the lime made from the magnesian variety is hot and injurious to the fertility of the soil.

	Bolsover.	Huddlestone.	Roach Abbey.	Park Nook.
Silica - - - -	3·6	2·53	0·8	0·0
Carbonate of lime - -	51·1	54·19	57·5	55·7
——— of magnesia - -	40·2	41·37	39·4	41·6
Iron alumina - - -	1·8	0·30	0·7.	0·4
Water and loss - - -	3·3	1·61	1·6	2·3
Specific gravities of dry masses -	2·316	2·147	2·134	2·138
——— of particles - -	2·833	2·867	2·840	2·847
Absorbent powers when saturated under the exhausted receiver of an air-pump - - - -	0·182	0·239	0·248	0·249
Disintegration — quantity of matter disintegrated - - -	1·5 grs.	1·9 grs.	0·6 grs.	1·8 grs.
Cohesive powers - - -	117	61	55	61

Name of Quarry from whence the Specimen was procured.	Weight in ordinary State in Grains.	Weight when well-dried in Grains.	Weight when saturated with Water in Grains.	Weight of Water absorbed in Grains.	Bulk of Water absorbed; 2 Cube Inches considered as Unity.	Weight of Particles disintegrated in Grains.	Cohesive Powers. Weight producing First Fracture.	Cohesive Powers. Crushing Weight.	Specific Gravity of the dry Specimens.	Specific Gravity of the solid Particles.	Bulk of Water absorbed; total Bulk considered as Unity.
Bolsover -	4890·8	4881·4	5042·0	160·6	0·079	1·5	70	117			
Ditto -	5052·2	5043·0									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·316	2·833	0·182
Huddlestone	4493·5	4491·4	4735·0	243·6	0·120	1·9	34	61			
Ditto -	4447·4	4445·9									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·147	2·867	0·239
Roach Abbey	4408·3	4406·0	4754·7	348·7	0·172	0·6	24	55			
Ditto -	4424·6	4422·5									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·134	2·844	0·248
Park Nook -	4356·6	4336·3	4784·7	448·4	0 221	1·8	26	61			
Ditto -	4519·2	4509·3									
Ditto -	- -	- -	- -	- -	- -	- -	- -	- -	2·138	2·847	0·249
Results of experiments upon cubes of 2-inch sides in duplicate.									Results of experiments upon cubes of 1-inch sides.		

The purity of all the limestones is readily determined by measuring the quantity of carbonic acid which is evolved during their solution in dilute nitric or muriatic acid: perfect carbonate of lime loses as much as 46 per cent, and when a smaller proportion is driven off, we may infer that there is less weight of calcareous carbonate. Marls or other earths containing lime may also be similarly tested by effervescing them with acids.

Statuary Marble—primitive Limestone.—Of this entire mountains are sometimes formed: in other instances it is found in beds; its specific gravity is 2·7; it can be sawn into thin slabs, and will receive a brilliant polish: these qualities are only found in three varieties of limestone, the saccharoid, foliated, and the carboniferous: it never contains the remains of organised bodies, but sometimes quartz, mica, hornblende, and other substances.

The white marble of Carrara is a fine grain, even and close, of equal colour, resembling white sugar; crystals are occasionally embedded in it, which prevent the working of the chisel: when diversified with spots and greenish or greyish veins, it is called *Cipollinaccio;* that of a coarser grain resembling salt, and thence called *Saligno*, is more difficult to work, and often contains a great deal of moisture: those which sound like a bell under the tool are called *Campane;* being exceedingly dry they are very hard. As these marbles are blasted, it is common to find them shaky in the interior of their mass, and containing veins: the Carrara marble will not admit of so fine a polish as that of Paros, but most modern statues are formed of it; probably the situation of the quarries affording greater facility for the working and transport. The Paros statuary is milk-white, greyish, and opaque; its texture varies from fine-grained to coarse; it is more difficult to work than the fine Carrara. The true Paros, with crystalline grains, is that which the Roman masons called *Marmo greco a specchioni;* that which they designated Paros is probably *Coralitique.* Pliny says that several marbles exceeded the Paros in whiteness; the Luni or Carrara had this advantage over it; but as this was the case with several others, it would be difficult to decide which were from Carrara and which from the Greek quarries. The works executed in Parian marble retain all the delicacy of wax with the soft lustre of their original polish.

The Pentelican marble obtained from the mountains in the neighbourhood of Athens, and exclusively used in the temples there, is of a yellowish white, close-grained, frequently interspersed with greenish stripes, which causes it to decompose when exposed to the air; it is found in beds, and so easily separated that the ancients used it as bricks and tiles; the Romans call it *Marmo cipolla;* but it must not be confounded with the *Cipollino*, or marble of *Caryste*, which is undulated from a greyish white to green, and is not a statuary marble. The quarries at Pentelicus were admirably situated both for working and transporting the blocks of which the beautiful structures at Athens were constructed; being at a considerable elevation, a regular inclined plane was made from the entrance of the quarry to the city, and masses of marble were moved upon rollers with little labour, care only being required to guide them. The various tinted marbles, or those having coloured veins, are of the same crystalline character, affected by an oxide of iron; but the blue and green tints are occasioned by minute particles of hornblende, as in the slate blue variety called *Turchino.* The black marbles receive their dark colour from charcoal mixed occasionally with sulphur and bitumen.

The Giallo Antico is a beautiful marble, of a regular yellow colour with light violet veins; it is extremely rare, and is supposed to have been brought from Numidia; there are several varieties; the black marble of the ancients called after Lucullus, from his having introduced it, was a very fine unmixed black; when exposed to a high temperature in an open crucible it burns white; with sulphuric acid it forms a black-coloured mass, and when dissolved in nitrous and muriatic acids it leaves an insoluble black-coloured substance; it is composed of

Lime	53·38
Carbonic acid	41·50
Black oxide of carbon	·75
Magnesia and oxide of manganese	·12
Oxide of iron	·25
Silica	1·13
Sulphur	·25
Potash and water, &c.	2·62
	100·00

The Rosso Antico is an Egyptian marble, the quarries of which are said to have been on the borders of the Red Sea; the best specimens are of a deep red without either black or white veins; the grain is very fine, compact, and takes a fine polish; it seems to be dotted or strewed over with very fine grains of sand. It has been occasionally used for the purpose of sharpening tools; pieces of it for this application have been found in the excavations of Herculaneum and Pompeii.

The Verde Antico is a kind of brescia, whose base or cement is a mixture of talc and limestone, the dark green fragments consisting of serpentine with spots of a lighter shade, pure white and fine black; the colours should be very distinct to constitute a fine specimen. It was found in Laconia and Thessalonica; several columns are extant, of great beauty and of large dimensions.

The Cipollino has greenish rings or zones produced by green tale; the fracture is granular and shining.

Alabaster — Sulphate of Lime. — There are two varieties, the gypseous, which is a semi-crystalline sulphate, and the calcareous, which is a carbonate. The word alabaster is derived from the Greek, and signifies vases of perfumes, called at first alabastra, from having no handles, and this kind of stone being often used for the purpose the name became applied to it. The Oriental alabaster is a carbonate of lime, frequently variegated with beautiful colours, and is suseeptible of a high polish.

The common alabaster is composed of sulphuric acid and lime, though some varieties effervesce with acids, and contain a portion of the carbonate; it is much softer than marble, and usually forms the lowest bed of the gypsum quarries. At Carrara it is worked into vases, statues, and ornamental models, &c.; the hardest variety is preferred, particularly that which has a granular texture and a pure white colour; it does not polish so readily as marble, but it is easier to work. When carved it is smoothed down with pumice-stone, and afterwards polished with a mixture of chalk, soap, and milk, the hand being used to give it the last finish.

Granite ranks as the most durable among all the stones selected for the purposes of building, but it is difficult and expensive to work. The Egyptians employed this material in enormous masses: we have an account of an edifice hewn out of a single mass of granite, and moved from the city of Sais to the Isle of Elephanta, which, after deducting the void, is stated to have been upwards of 1222 cube cubits; its weight therefore would be upwards of 200 tons. The temple of Latona at Buto, mentioned by Herodotus, had the sides of a single stone, and the roof also in one piece.

The obelisks at Rome were quarried in Egypt, and transported at a great cost to the imperial city: of twelve which remain eleven are erect; they are a large-grained red granite, covered with hieroglyphics with the exception of three, and the granite of which they are composed is of so imperishable a nature, that after exposure to the action of the atmosphere for 3000 years, the hieroglyphics are still entire; they are in relief, but this was effected by sinking the surface of the granite around them, the sinking forming the outline; so that the figure, not projecting beyond the ordinary surface, is not exposed to decomposition, but in some degree protected. Poggio mentions that in 1430, these obelisks were all prostrate, with the exception of that of the Vatican, which was in one single block, unbroken, and without hieroglyphics; its height is about 84 feet, and its weight may be taken at 300 tons. It was moved by Fontana to the Piazza of St Peter's, and is the largest mass of granite known to have been applied to purposes of art, with the exception of that at St. Petersburg for the statue of Peter the Great. Granite was also largely employed by the Romans for the shafts of columns; those of the Pantheon are of one single piece with statuary marble, capitals, and base. Egypt, as well as the island of Elba, supplied them with abundance of this material, not only for their temples, baths, and fori, but also for fountains, the basins of which were hollowed out of large masses.

In England, granite does not seem to have been brought into use for the purposes of construction much before the commencement of the present century. The bridges at London over the Thames, erected by the Messrs. Rennie, may perhaps be mentioned as instances of its first application upon a large scale: its beauty and durability render it superior to all other material for works considered national, or intended as monuments of art to be bequeathed to future generations. In the selection of granite, attention should be paid to its quality, which evidently varies as it is produced from different quarries, that obtained from the surface being usually more or less in a state of decomposition: the quartz, mica, and felspar, composing the granite, do not seem to be held together by any base or cement, and the size of the crystals or grains differs in the various specimens, as do the proportions of the ingredients themselves. As the quartz, mica, and felspar, contain several elementary substances, to determine their constituents it is necessary to reduce a given quantity of granite to a powder, and then to fuse it in a platinum crucible with three or four times its weight of alkali, which will decompose it by uniting with one or more of the constituents. The mass so fused is soluble in dilute muriatic acid by the application of different re-agents; the constituents are precipitated, after which it may be filtered, carefully dried, and weighed.

The quartz may be considered pure silex; it is an indestructible body, sufficiently hard to scratch glass, and when struck with steel will produce fire; it is also infusible before the blow-pipe; it is whitish, yellowish, or greyish white. The form of its crystals are generally six-sided prisms or pyramids; they may be cleared parallel to the faces of the primitive crystal, which is a rhomboid; its specific gravity is 2·6 to 2·7.

Mica, as found in granite, is confusedly crystallised, and its primary form is said to be a right rhomboïdal prism; its colour varies from white, yellow, green, brown to almost black; in some instances it is so very transparent that it is used as a substitute for glass; its specific gravity is about 2·0 to 2·5. The analyses of mica vary, but Klaproth gives that of two varieties, the first from Zinnwald, the latter from Siberia.

Alumina	20·00	34·25
Silica	47·00	48·00
Oxide of iron	15·50	4·50
—— of manganese	1·75	0·00
Magnesia	0·00	0·50
Potassa	14·50	8·75
	98·25	96·00

Felspar in the granite is found in rhomboidal crystals, and can be cleaved with facility into an acute-angled parallelopipedon; its prevailing colour is white, sometimes flesh red and green; its specific gravity is 2·54: when heated it gives out no water; before the blow-pipe it fuses into a white enamel; it is insoluble in acids.

Silica	64·50
Alumina	19·75
Potassa	11·50
Oxide of iron	1·75
Water	·75
	99·25

From an examination of these ingredients, it appears that granite contains more than ⅔ its weight of pure silica, and the remaining third is alumina, potassa, and oxide of iron: the felspar is the first to decompose, the next is the mica, but the quartz is imperishable. The quartz may be known by its grey and translucent colour, the felspar by its greyish white or flesh-red tint, and the mica by its grey or black colour.

On the Resistance of Stone to the Crush. — The resistance of stone to the crush may be considered first with respect to the weight it is capable of sustaining; second, supposing it placed between two horizontal surfaces, what weight could it carry without being crushed or split under it? third, in supposing it held vertically by the upper part, what weight could be suspended at the lower extremity without the stone yielding? It very rarely occurs that weights are suspended at the extremities of the stones; on the contrary, whether in the construction of piers or of the vaults, they are pressed between two parallel surfaces. Although some experiments have been made on the resistance of stones held at one of their extremities, their strength, when thus applied, is not yet ascertained; but not so the resistance of stones bedded level; our knowledge on this subject, if not complete, is very far advanced.

But a short time has elapsed since it was first attempted to discover the weight stones are capable of sustaining; and if we consider the great thickness which the ancients have everywhere given to the points of support of their edifices, we shall be induced to think that they had little idea of the resistance of the material they used. The boldness of the architects of the middle ages, who sometimes carried immense masses on slender and lofty columns, would on the contrary lead us to believe that they had studied the properties of stone in this respect; but no traces remain to us of any researches, and, according to the state of the sciences in the ages in which they worked, it is natural to believe, that, without much reflection, they sought to excel each other in lightness till they arrived at limits which they might possibly have carried still further. As an example of the smallest surface of the points of support of Gothic architecture, we may cite two columns in the church of Toussaints at Angiers; their diameter is only 12 inches, and their height 25 feet; they support pointed arches, the mouldings of which are in freestone, and the weight carried by each is 35 tons.

The discussions to which the dome of *St. Genevieve* gave rise were the occasion of the first experiments made on the resistance of stones; Mons. Patte published in 1770 a memoir, in which he raised doubts on the solidity of the piers of this dome, and asserted that they had not sufficient surface to enable the tower which supported the cupola to resist the thrust. Mons. Gauthey replied the following year to these assertions, showing that they were not in agreement with the rules then known for calculating the thrusts of vaults, and proved by applying these rules in a more exact manner, not only that the thickness of the piers was sufficient to carry the vaults projected by Soufflot, but that the solid mass of masonry might be suppressed, and the columns attached to them only preserved. This assertion supposed, however, that the stone of which the columns were composed would not crush under the weight it would have to sustain; and as this latter difficulty could not be resolved without knowing exactly the strength of the stone, Gauthey undertook for this object experiments which might then be regarded as entirely new; they were published in 1774, in the Journal de Physique of the Abbé Rozier.

The construction of the piers of the church of St. Genevieve, considered with relation to

the strength of the stone compared to the weight which it supports, is bolder than that of the columns of the church of Toussaints at Angiers: these piers are constructed in hard stone of *Bagneux* in the lower part, and in that of *Mont Souris* in the superior part: the beds formed of the stone of Bagneux are considerably split; those in the stone of Mont Souris have resisted much better. The weight supported by a surface of 9 square inches in the pillars of the church of St. Genevieve is 16 cwt.; the weight under which a cube of 2 inches in hard stone of Bagneux was crushed is 137 cwt.; the weights supported by a similar cube in the stone of Mont Souris was 68 cwt. Hence the pressure supported by the stone of Bagneux in the piers of St. Genevieve is from eight to nine times less than that which is necessary to crush it, and the pressure supported by the stone of Mont Souris is only four times less; it may then appear astonishing that the latter has resisted better than the preceding.

The pressure supported by the key-stone of the vaults of the bridge at Neuilly is 127¼ tons per 3 feet 3 inches of length, and it appears that the weight carried is fourteen times less than that which will crush it: but we must observe that by the settlement in these vaults, the weight is not equally distributed on the whole height of the key; the principal effort is near the upper edge, and although we cannot exactly judge of the total weight carried by the adjacent parts of this *arris*, we may presume, on account of the great flatness of the vault, that this portion is very considerable, and that the bridge of Neuilly is as bold an edifice in this respect as it is in every other.

We may add from Mons. Rondelet an indication of the pressure exercised on a surface of 9 square inches in the edifices regarded as the boldest: —

	Pounds Avoirdupois.
Piers of the dome of St. Peter's at Rome	1022½
Piers of the dome of St. Paul's at London	1190
Piers of the dome of the Invalides	922
Piers of the dome of St. Genevieve	1840
Columns of St. Paul's without the walls	1235
Piers of the tower of the church of St. Méry	1837½
Columns of the church of Toussaints d'Angers	2767½

In the pier of the Chapter House at Elgin the stone supports a weight of 5½ tons on each 9 square inches: it was formerly loaded with a heavy roof covered with lead; the stone, which is a red grit, has resisted this pressure for several centuries; it is estimated that the resistance is from 7725 lbs. avoirdupois to 23925 lbs. on 9 square inches, whilst that of brick is 9150 lbs.; consequently, 1520 lbs. for 9 square inches is a pressure which may be admitted with security for the voussoirs of an arch. This pressure would be perhaps too considerable for calcareous stones, and as a general rule, stones should not be made to carry a weight more than $\frac{1}{10}$ of that which has crushed them in small experimental cubes; this weight would be too great if we were not assured that the pressure would be equally spread over the whole surface of the joints: the voussoirs of the arches near the key, and the points of fracture, are exposed to inequalities in the partition of the powers they exert as supports, and we shall see by-and-by how we can appreciate these effects. The parts of a block of stone comprehended between the beds of a quarry are not exactly homogeneous: experiments have shown that the weight and the specific résistance are more considerable in the middle of the stone, and diminish proportionably in its approach to the upper and lower beds.

By the experiments of Gauthey it appears, that the strength of the stone augments in a greater relation than the surface of its base; the results reported by Mons. Rondelet agree in general with this assertion. But as no experiments were made on surfaces of any considerable dimension, or differing much from each other, it does not appear possible to judge exactly of the manner in which the resistance of the stone does augment relatively to the surface of its base, and it is proper in the application to suppose the relation constant, which, moreover, cannot induce any dangerous error as this hypothesis, is favourable to the resistance.

We know a little more positively the influence which form has on the resistance of stone. The experiments which have been made with a view to discover this influence have shown that the different solids, the bases of which had equal area, resisted best, as their figure approached a circle; and in general that for figures differing from each other, the resistance was nearly in the inverse ratio of the perimeter.

When the base of solids remains the same, height influences their strength: a very thin stone easily fractures: if it is in the form of a cube it carries a considerable weight, but if the height is augmented, the strength, which first augmented also, finishes by diminishing; if a vertical prism is divided in several parts longitudinally, it will resist less than if it were in a single piece.

On the Pressure to which Stones are exposed in Vaults. — The thickness which it is necessary to give to the vaults of bridges involves many considerations: and the pressure to which

the voussoirs are exposed, and the degree of resistance of the stone, deserve enquiry; it is necessary to direct our particular attention to these objects when we are projecting arches of considerable span.

Suppose Q the horizontal thrust of the arch, a the pressure that the two halves exert against each other, and which is the greatest possible force it will be necessary to apply horizontally in N to prevent a portion, mn and N M, of the arch turning from top to bottom on the edge m.

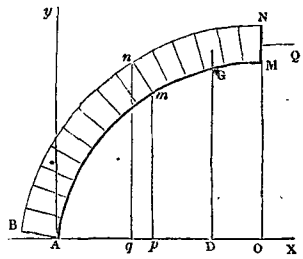


Fig. 594.

The co-ordinates A O, N O, of the point M, counted from the point A, are designated by a b, and the length of the joint M N by c. The co-ordinates A p, p m from the point m, are named x and y, the length mn of the joint z, and the angle which this joint forms with the vertical, θ. We represent by G the weight of the portion of the arch mn N M, as well as the parts of the construction which it supports, and by cc the horizontal distance from the centre of gravity of this weight to the point A. The value of the horizontal thrust at Q being known, we shall easily ascertain the pressure exerted perpendicularly against any joint, mn; in effect, this pressure can be no other than the result of the forces Q G, to which is submitted the portion of the vault mn N M, discomposed perpendicularly at mn; that is to say, it is expressed by

$$G \text{ Sin. } \theta + Q \text{ Cosin. } \theta$$

It is not, however, right to consider the horizontal thrust Q a force applied to the arris N, as the voussoirs at the summits of vaults necessarily lean against each other through the whole, or a portion of the height of the superficies of the joint; the pressure then being extended over a certain space below the arris N, it acts to prevent the descent of the portion of the vault mn M N, with an arm of a lever less than is supposed, when we consider it as applied in N; consequently we find, as the effect of this supposition, the value of Q smaller than it really should be.

The value of the normal pressure exercised on each joint should be exactly known, or we cannot deduce from it the efforts supported by the stone, since we are ignorant of the manner in which this pressure is spread over the surface of the joint; far from being able to admit that the pressure is equally distributed over all that surface, we know on the contrary that in all the arches, with the exception of a small number of joints, the pressure is principally exercised near one of the edges: this circumstance takes place above all at the summit, when the pressure exerts itself near the upper edge; at the joints of rupture, placed in the haunches, when it exercises itself near the bottom edge; and at the inferior joints below the springing, when the pressure exerts itself at the exterior edge. We suppose here, conformably to what has so often taken place, that the inferior parts of the vault have a tendency to thrust outwards.

The manner in which the pressure is spread over the surface of the joints is besides more uncertain, as it depends on the precautions with which the voussoirs are cut and placed, on the disposition of the wedges, on the consistency of the mortar, and the settlement of the vault, according to which the joints are more or less open.

CHAP. IV.

BRICKS AND TILES.

Where stone cannot be procured, bricks form an admirable substitute, being easily made from clay or argillaceous earth, which is found in most situations where stone is wanting: some advantages are derived from the use of this material over stone, which is not obtained from the quarry in a state or shape fitted for use, whilst the brick is of a convenient size, and easily carried to the place where it is employed. An absorbent brick readily adheres to the mortar in which it is bedded, and in a short time becomes a solid mass; whilst it often happens that hard stones are less adhesive, and their surfaces do not combine with the mortar in which they are laid.

Unburnt bricks are of great antiquity: the first were probably masses of clay, dried in the air by exposure to the sun; afterwards these masses were moulded into regular and uniform shapes, improved also in strength by mixing chopped straw with them: such bricks were not calculated to resist the humidity of our climate, although some found among the ruins of Babylon are as durable as if they had been burnt, which is entirely owing to the dryness of the air.

The remains of what is considered a part of the famous tower of Babel are perhaps among the most ancient specimens of unburnt brick: these bricks are 12 inches square, and 4 inches in thickness, are bedded in bitumen mixed with sand, the joints of which are about 8 inches in thickness; and although they have stood the exposure to the dryness and heat of the climate, when soaked in water have quickly decomposed, which is sufficient proof that straw, reed, and such vegetable matter mixed with the clay, do not constitute a sound brick: at Bagdad, where the bitumen is obtained from a lake in the neighbourhood, bricks are still used in most of the buildings.

The immense edifices of unburnt brick constructed by the Egyptians remain almost entire: one distant about 10 leagues from Cairo, and measured by Dr. Pococke, in 1738, was about 150 feet in height, with its base rectangular, one side being 210 feet and the other 157 feet. This brick pyramid was supposed to be that mentioned by Herodotus as built by Asychius, who is said to have inscribed on it the following: "Do not disparage my worth, by comparing me with pyramids composed of stone: I am as much superior to them as Jove is to the rest of the deities; I am formed of bricks, made of mud that adhered to the ends of poles, and drawn up from the bottom of the lake."

These bricks are composed of a black, argillaceous earth, containing small pebbles, shells and chopped straw, and were of two dimensions, the largest 15 inches long, 7 inches broad, and about 4½ inches thick.

The Greeks as well as the Romans used, as we have seen, unburnt bricks: Vitruvius mentions the wall of Athens, on the sides towards Hymettus and Pentelicus; the walls of the temples of Jupiter and Hercules, the columns and entablature of which were of stone; the palace of King Attalus at Tralles, that of Crœsus at Sardis, and of Mausolus at Halicarnassus: that author also describes the manner in which unburnt bricks were made, and observes that gravelly, pebbly, or sandy clay is unfit for the purpose, and that the most proper is a red earth, of a chalky nature, or containing sand; and that the proper season for making them is the spring and autumn, as they dry more equally. When plaster is laid on bricks which are not perfectly dry, they shrink, and the plaster no longer adheres to them: the inhabitants of Utica would allow no bricks to be used which were not at least five years old, and had been approved by a magistrate.

The three sorts of bricks in use were the doron, the tetradoron, and the pentadoron.

The word doron signifies palm, designating a gift that might be borne on the palm of the hand, and it is supposed that the Roman palm was equal to it. The tetradoron is a cube of four palms, and the pentadoron five: there were half bricks of each sort: the least thickness the Greeks are supposed to have given to their walls was that of the doron, or one brick, to their ordinary walls a brick and a half, and to their thickest two bricks. In building a wall there are alternate courses of whole bricks and half bricks, so that the joints are regularly broken.

In neither Athens nor Rome are found any remains of unburnt bricks, and the form of those mentioned by Vitruvius is not quite certain, though it is generally believed that they were cubical; it does not seem very practicable to build a wall and keep the courses regular where the three varieties are to be used; they seem intended for as many different kinds of work. The unburnt bricks still used by the nations of the east are made by treading the clay with the feet, and mixing chopped straw, after it has been duly prepared; it is then

put into small wooden moulds, and, in order to give them firmness, they are plunged into a vessel of water, in which is a quantity of chopped straw, and after two or three hours' immersion, they are laid out in the shade, where they remain until they become dry. When walls are constructed with them they are coated with a layer of clay and chopped straw, which protects them from the rain; sometimes a coat of lime and plaster, beaten and mixed together is substituted, where a better effect is desired.

Brick-making. — The earth usually selected by brick-makers is of a tenacious character, and partakes of the quality of loam; a stiff clay makes a brick that falls to pieces in burning, whilst a milder earth is made by adding a quantity of sand to that which is too strong. The clay dug in the autumn is wheeled in barrows to a piece of ground previously levelled to receive it, where it has a quantity of breeze added, which renders it partly combustible, when submitted to the heat, which converts the clay into a brick. It is necessary that the brick should become red-hot throughout, and which would be difficult without the breeze, which also gives colour, hardness, and durability. After this mixture of clay, sand, and breeze is rendered ready for use by being worked together with the spade, and continually softened by water, it is exposed to the action of the frost, and usually small heaps are thrown up, so that the weather may penetrate them, and form one uniform, soft, and yielding mass: it is then tempered by adding water, or spreading it to dry; then the whole mass is pressed down, and preserved by a covering to prevent the sun or air further affecting it.

The clay is now generally wheeled at the commencement of the spring from the place where it has been exposed to the action of the frost to the pug-mill, where chalk, sand, or other materials are incorporated with it, the mill being supplied with a quantity of water, which reduces the whole into a thin paste, running through a sieve or wire strainer into a reservoir formed for the purpose; when this is full the whole is suffered to subside, and the water is gradually drawn off: after it has acquired sufficient consistence, this finely divided paste is moved by barrows, and mixed with sifted breeze; a few days' exposure to the air makes it sufficiently dry for the moulder's use.

The pug mill is a conical tub, secured by iron hoops, about 6 feet in diameter at the top, and as much in height: the bottom is made of clay, or some other material impervious to water, and constructed so as to be perfectly firm and steady. The clay is put into it, and then, by means of revolving rakes, with iron teeth, like those of the harrow, and made in such a form that in their revolution they lift up the clay, which falls down again towards the bottom; the masses so separated, and supplied with abundance of water, are soon reduced into a paste. The whole is prevented from adhering to the bottom by a constantly revolving scraper, which allows the pugged clay to find its way to the orifice at the bottom, where it is discharged.

A long beam of timber, keyed on the upright shaft, has a yoke, to which a horse is attached, that walks round in a track not exceeding 16 feet in diameter; if larger the proper motion would not be maintained. A pump worked by hand, or by the machinery, throws the required quantity of water into the mill: the clay is put in from barrows, wheeled up a platform made for the purpose.

The Moulder's Bench is usually attended by a lad or assistant, who cuts the clay into portions sufficient to fill the mould; these are taken up by the moulder, and thrust into it, which is previously passed through a mass of sand, to prevent the clay from adhering to it: after the clay has been well forced down, a flat wooden strike is made use of to remove all that is superfluous; the brick is then turned out upon a board, and taken away by a boy to the track in a barrow, covered with thin laths or strips of wood: one moulder's bench will supply 5000 bricks or more per day.

The bricks are then laid upon each other in the *hacks*, arranged on their edge, and placed diagonally, so that the sun and air pass freely around them; they remain here some time, after which their position is changed, and in a week or 10 days, if the weather be favourable, they are fit to be burnt.

The clamp is the general system adopted for burning them, which is formed by making a foundation of place bricks, and then arranging those to be burnt in layers, with a stratum of breeze or cinders, 2 or 3 inches in thickness between them.

A fireplace is generally at the west-end, about 3 feet in height, from which various flues branch out that run in a straight direction throughout the clamp; these flues, filled with coals or breeze, are placed at distances of 5 or 6 feet apart: when the weather is favourable a month is sufficient to burn off a considerable quantity.

Kilns containing 20,000 are in the country often preferred for burning bricks; these are made 13 feet in length, 11 feet in width, and 12 feet in height; the outer walls incline inwards as they rise, and are a brick and a half in thickness throughout.

The furnace is formed of three arches, which have apertures at the top to allow the heat to pass through to the charge, which is placed on a floor of lattice; a moderate and gentle heat is applied for the first three or four days, to drive off the water; the mouth of the furnace is then blocked up by a *shinlog* composed of brick, and room only left to

introduce the necessary quantity of wood for the purpose of maintaining the fire; when the flame has made its entire way through the whole of the layers, and appears at the top, the fuel is more sparingly applied, and in a short time the fire is suffered to go out, and the kiln gradually cools. Forty-eight hours is sufficient to burn off a kiln of bricks, if care is paid to the raising and slacking the heat, which requires some skill on the part of the burner.

Marls, or *malms, stocks, and place-bricks* are so named, according to their fineness or quality. The first is of bright uniform yellow colour, partly obtained by washing chalk with a fine clay; from these are selected the cutters for arches, which, from their fine texture, are calculated for rubbing.

Seconds is another term for a second quality of malm, which are used for gauged work, and the facings of walls.

Stocks are either red or grey, the first being the kiln-burnt, the other that usually from the clamp.

Place-bricks are of an inferior quality, and, from the fire not having thoroughly burnt them, are generally fit only for purposes of building where soundness is not a requisite.

Floating bricks, in imitation of those made by the ancients, were formed by M. Fabbroni out of a material which consisted of 55 parts of siliceous earth, 15 of magnesia, 14 of water, 12 of alumina, 3 of lime, and 1 of iron: this kind of brick does not become altered by fire, being infusible, and although it loses $\frac{1}{8}$ part of its weight, it is not in any way diminished in size: as these bricks are found to float on water, they have been very much used where lightness of construction was desirable.

Fire-bricks, used for furnaces and the lining of stoves where great heat is generated, are moulded in various parts of England. At Hedgerley, near Windsor, where the loam contains a considerable amount of sand, they were made in large quantities; Welsh lumps and Stourbridge bricks are a similar quality, and will stand the action of great heat.

Retorts for a variety of purposes are made with a mixture of clay and iron, particularly for the manufacture of gas; the iron retort receiving a casing of prepared clay, which permits the fire to act first on the clay, and thus prevents the rapid destruction of the metal.

Retorts or bricks made of one part pure clay and three parts of coarse and pure sand, slowly dried and annealed, will resist a very high temperature, and are not readily fused; but if in contact with any metals in a fusible state, which are suffered to oxidise, they will then act upon the earthy matter, and cause it rapidly to fuse.

A long continued white heat will soften the compound made of any of the siliceous and aluminous earths; therefore clay and sand are not so well adapted to bear a great heat as an entire clay; coarsely powdered and burnt clay being substituted for sand, the vessels which contain glass in the furnace, and which are subjected to intense heats, are thus made, and resist for a length of time the action of the saline fluxes they contain.

Windsor loam, or a mixture of clay and sand, made by beating a thin paste, is employed as a lute to unite the joints of fire-bricks, or to set them in instead of common mortar; and if it is required that vitrefaction should take place with the clay so used, borax or red lead, mixed in small portions, will produce the effect; such a compound will destroy the porosity of earthenware, when exposed to high temperatures.

The strength of brickwork depends entirely upon the manner in which the bricks are laid; at present the practice in England is confined to what is called Old English and Flemish Bond. The first, which is the preferable mode, has a course of stretchers, and then a course of headers; the latter is alternate header and stretcher.

In the Old English the stretching courses bind the wall together in the longitudinal, and the heading courses in the transverse direction; so that if any fracture occurs, it does not break at the joints, but as a solid mass.

The Flemish bond, introduced into England about the reign of William and Mary, is, however, frequently preferred, because it presents a more regular face; wherever strength is an object it should be rejected, and the old English practice followed. Each course being alternately headers and stretchers, should have every brick in the same course laid in the same direction, and in no instance is a brick to be placed its whole length along the side of another, but to be so situated that the end of one may extend to the middle of those it adjoins, except in the outside of the stretching course, where three-quarter bricks must be used, to prevent a continued upright joint in the face of the work: and where a wall crosses another at right angles, all the bricks of the same level course should lie in the same parallel direction, in order that the angles may be completely bonded.

In Flemish bond, to prevent the wall splitting, it is necessary to make use of iron hoops, in the horizontal joints between the two courses, and some bricklayers, to attain the same end, lay diagonal courses at certain heights from each other, but the latter system is far from efficacious; others lay all heading courses within the outside Flemish bond, making the face-work alternately of 9 and 4 inches in thickness; this prevents splitting, but destroys the stretching bond.

Tiles are formed of a reddish or grey-coloured clay, which fuses at a red heat: these clays are probably mixtures rather than compounds of silica, alumina, and water.

The common kind of tiles is made of the blue clay, obtained near London at a greater depth than the ordinary brick earth; this is excavated in the autumn, and exposed to the air during the winter, to properly temper it: after the tiles are moulded to their shape, they are burnt in kilns, surrounded by a conical structure with an opening at top.

A kiln 20 feet square, with 3 furnaces, is calculated to burn about 34,000 tiles at one time; the space which contains them above the arches of the fireplace being 14 feet 6 inches square, and about 8 feet in height, this square chamber being open at the upper surface: around it is built the frustum of a cone, with a clear diameter of 32 feet at bottom and 3 feet at top, the walls of which are of brick, 18 inches in thickness at bottom, and diminishing by three regular internal sets-off to 9 inches at the top: an entrance is usually left at opposite sides for the charging and unloading the kiln, the bottom of which is generally sunk about 10 feet below the ordinary surface of the ground, and a vaulted passage leads to the furnace, where the fuel is applied: such a kiln is adapted for the burning of bricks as well as tiles, and is found to answer for both admirably well.

The Earth used for making tiles should be pure and tough, and free from any foreign matter: after constant turning over and tempering, it is brought to a proper consistence and moulded into the desired shape.

Plain Tiles are usually made $\frac{5}{8}$ of an inch in thickness, $10\frac{1}{2}$ inches long, and $6\frac{1}{4}$ wide, weighing from 2 to $2\frac{1}{2}$ pounds each: these when laid lap over each other, and the part uncovered is called the gauge, which is generally $6\frac{1}{2}$ inches: when so laid, 740 tiles will suffice to cover 100 superficial feet; they are hung upon the lath by two oak pins inserted in holes perforated by the moulders before burning.

Plain tiles are now made so that they may be placed side by side, in courses perfectly flat, without overlapping: this is a far more economical method, decreasing the weight nearly half: a groove is run in the edges which receives a corresponding fillet, both at the sides and at the top and bottom, communicating with each other, and should any water enter the joints it is carried down to the eaves in a continued line.

Pan Tiles, first used in Flanders, have a wavy or convex and concave surface one way, and are made $14\frac{1}{2}$ inches in length and $10\frac{1}{2}$ inches in breadth; their gauge is usually 10 inches, and 170 are sufficient to cover 100 superficial feet; these tiles weigh from 5 to $5\frac{1}{4}$ lbs. each.

Ridge and Hip Tiles are formed cylindrically, 13 inches in length; and girth 16, weighing on an average 5 pounds.

Gutter Tiles are nearly the same size and thickness.

Mathematical Tiles, for covering the upright surface of cottages, instead of lathing and plastering the outsides, are much in use in the counties of Kent and Sussex: these tiles are intended to resemble courses of brick, and are made to overlap each other; the face of each consists of two planes, the size of a common brick, and when placed in their proper position, they form a double thickness of tile; they are nailed on, and a fine mortar is introduced where they rest on each other, which is pointed in the same manner as ordinary brickwork.

Weather Tiles differ from these: they lap over each other, and are made of various patterns, but having their size and thickness that of the common plain tile; they resemble the plates of chain mail, when in their position, and their exposed edges often receive a variety of outline, and form great diversity of pattern; when put on with proper nails, they are found very durable and keep out the weather. Various machines have been invented for the manufacture of tiles, one of which, patented by Mr. Hunt, has two wooden cylinders, round which revolve bands of cloth, which press the clay into one regular thickness throughout; this is conducted by a continued web over a covered wheel, curved on the rim, which gives the cylindrical form to the tile; they then pass through iron moulds, and are cut off to the length required.

The Flat Tiles are made in somewhat similar manner: by this machine drain tiles, and the sole pieces on which they rest, are moulded with the greatest correctness.

The Brick-making Machine, patented by the same inventor, has also two cylinders, each covered with an endless web, which are so placed that they form a sort of hopper on their two upper cylindrical surfaces, the ends being enclosed by two iron plates: well tempered clay from the pug mill is thrown into this hopper, and at the lower part it acquires the form and dimensions of a brick: beneath is worked an endless chain, by the movement of the cylinders, and at various marked intervals are laid the palette boards under the hopper; the clay is brought down by a slight pressure, and enters a frame, which has a wire stretched across it, which projects through the mass, and cuts off the requisite thickness; this is immediately removed by the forward motion of the endless chain; and this operation is renewed as often as a new palette board is advanced under the hopper: such a machine produces about 1200 bricks per hour, and is worked by two men and three boys.

Bricks usually made with machinery are found to dry with more difficulty, in con-

sequence of the great pressure that has been made use of; the clay, being more compact, dries on the outside long before the centre parts with its humidity, and in consequence the surface is apt to peel off. This machine does not exercise more than a slight pressure, and the bricks made with it are uniform in size and quality.

The Marble Tiles, which covered the Greek and Roman temples, have been imitated in clay, and when properly made have an elegant effect: flat tiles with raised sides extend

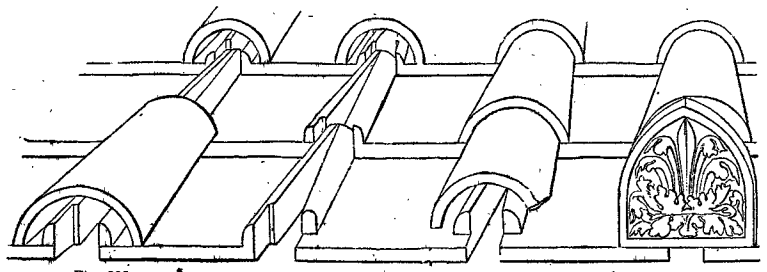


Fig. 595. ROMAN TILES.

from rafter to rafter, the upper ends having a rib that enters a groove formed on the underside of the tile placed above it; after these are laid, the joints in the direction of the rafters are covered with other tiles, formed like the half of a frustum of a cone, and made to lap over each other; the ends over the eaves or cornice are closed by an ornament, as an eagle, honeysuckle, or flower.

In other examples the long joints are covered by rib tiles, with a fine arris or edge at the top, which is calculated to produce considerable strength, and keep out the weather equally well.

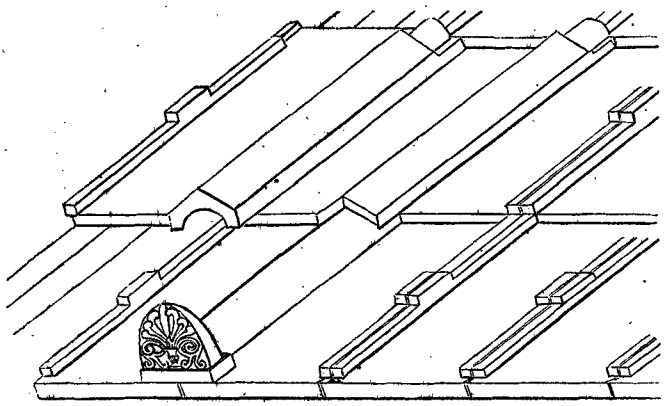


Fig. 596. GREEK TILES.

The architects in Paris have made use of such to cover both public and private buildings, and some of the manufacturers produce them in all their varied forms by machines of a very simple kind: those which covered the temple of Jupiter Stator at Rome were of marble, and of considerable dimension, and since their discovery they have served as models for imitation.

The Sunk Tile, with its lateral raised fillets, being laid side by side, had the upper edge overlapped by the succeeding course; the longitudinal joints, or those in the direction of the rafters, were covered by a rib, cut on the underside to saddle the fillets of the two tiles with the joint between them. The lower ends were covered by a perpendicular ornamental tile or antifissa, the sculpture of which constantly varied: on some of those at the Temple of Vesta at Rome, which the writer discovered, is the representation of an eagle, and on others the honeysuckle.

In Flanders, where moulding in clay was at a very early period carried to great perfection, are many varieties of pattern; and they are contrived not only to produce a good effect as they lie, but to keep out the weather: the wavy, which is the most common, are laid on or taken off with very little trouble; they are made with a projecting knob

on the underside, for the purpose of hanging on the lath; the tail of the next overlapping, and by its weight keeping the other in its place.

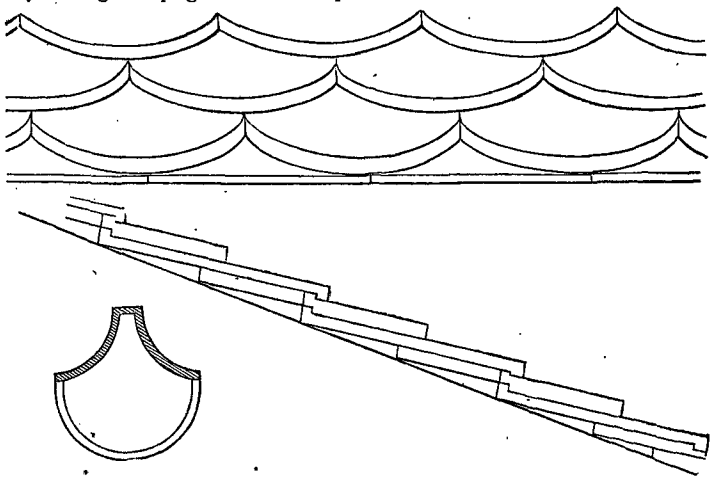


Fig. 597. SEMICIRCULAR FORMED TILES.

The semicircular formed Tile lies like the plates of chain mail one over the other, and forms an admirable covering both for effect and utility. In these the fillet which bounds

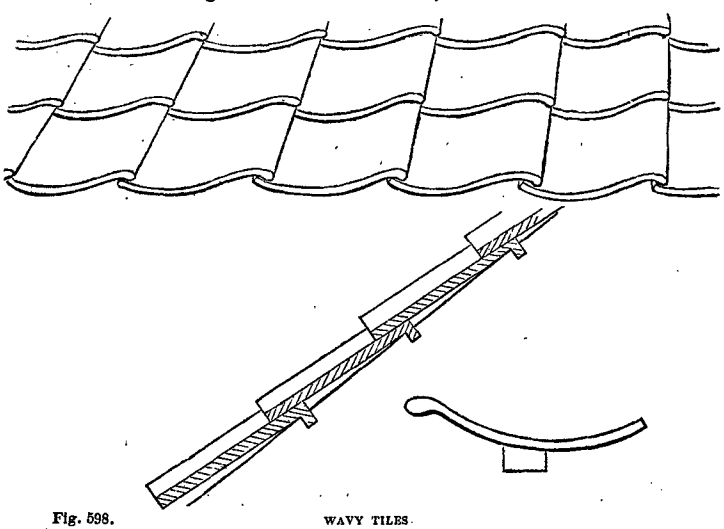


Fig. 598. WAVY TILES.

the concave sides is elevated above the tile, and that dotted is raised beneath it, so that when placed it covers the others and keeps all the joints tight, as well as serves to hang them all together; this is a very ingenious and excellent mode of forming the tile.

Most buildings might be improved by making their covering more ornamental, and when a graceful form is given to the tile, it contributes greatly to the effect. In the example three are made use of, and that which lies undermost forms the gutter, which conveys away the water that falls upon the roof; the wavy character of the arrangement is well adapted for rustic building, and worthy of imitation.

These plates of clay baked in a kiln have been long used for covering the roofs of houses, and the moderns have generally adopted only one kind, whilst the ancients employed two: that placed in regular rows was called *imbrex*, and that which covered the joints of two so

laid side by side, the *tegulæ*; the ends at the eaves being finished with those ornaments we have termed the antefissæ. Pliny mentions them under the term *personæ*, probably from their resemblance to masks, and says they were invented by a Sicyonian potter named Dibutades, who was established at Corinth, where they were called *protypes*, from being stamped in front only: other tiles fixed upon the ridge, executed by the same artist, were termed *ectypes*.

Many very ornamental tiles were made use of, some of which were covered with plates of metal, either silver or bronze.

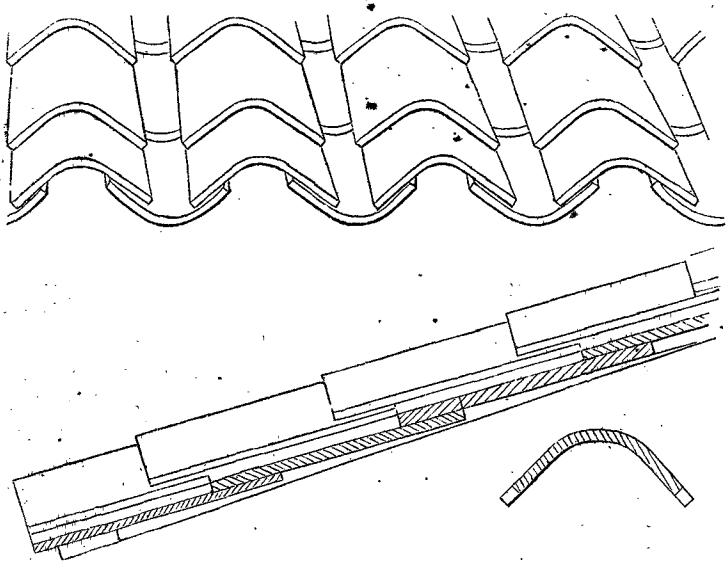


Fig. 599. CONVEX TILES WITH COVERED JOINTS.

A more simple application consists of forming the tiles in such a manner that the covering to the joints can be dispensed with; this is accomplished by making the lower tile

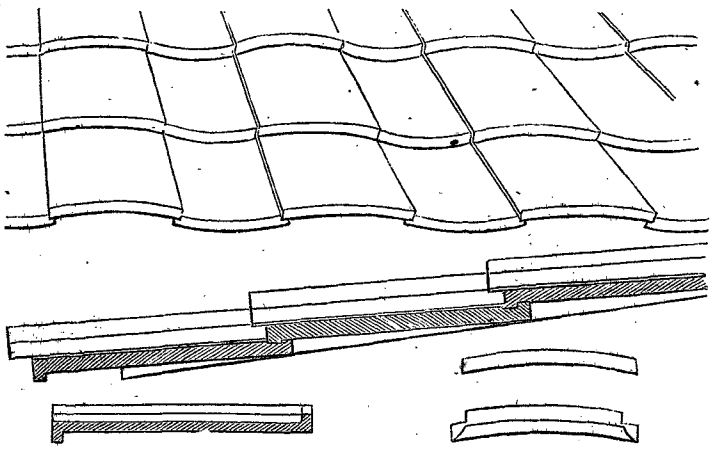


Fig. 600. CONVEX TILES LAID WITHOUT COVERED JOINTS.

with grooves at the edges, in such a manner that a portion of the upper may enter and keep out the weather.

Tiles are sometimes laid diagonally, and with an undulating surface: the joints are then sufficiently covered, and do not require any further protection.

Throughout France there are many varieties of pattern, and in laying their plain tiles, particularly in Paris, they vary the arrangements; in some instances, a square plain tile is laid

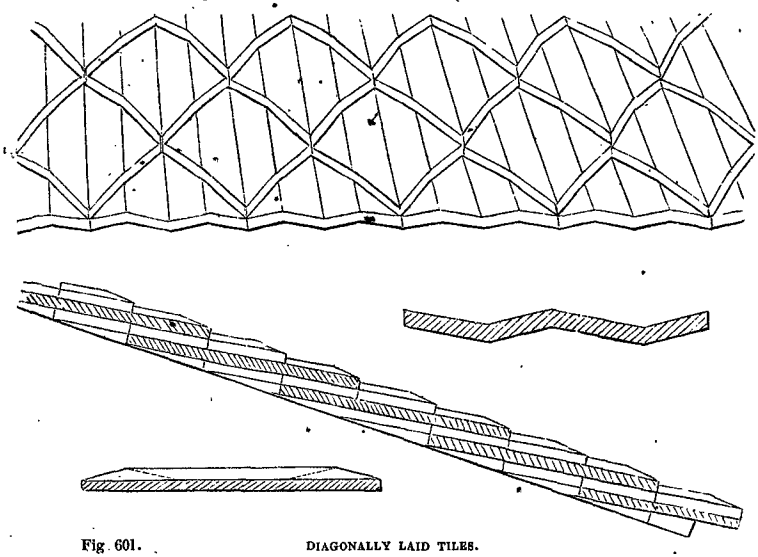


Fig. 601. DIAGONALLY LAID TILES.

diagonally, in others they have undulatory or polygonal surfaces, forming channels to conduct off the water, and producing a good effect.

The Tiles, which cover some of the abattoirs, are made in a similar manner to those manufactured in Burgundy; a concave tile is laid, with its position alternately reversed,

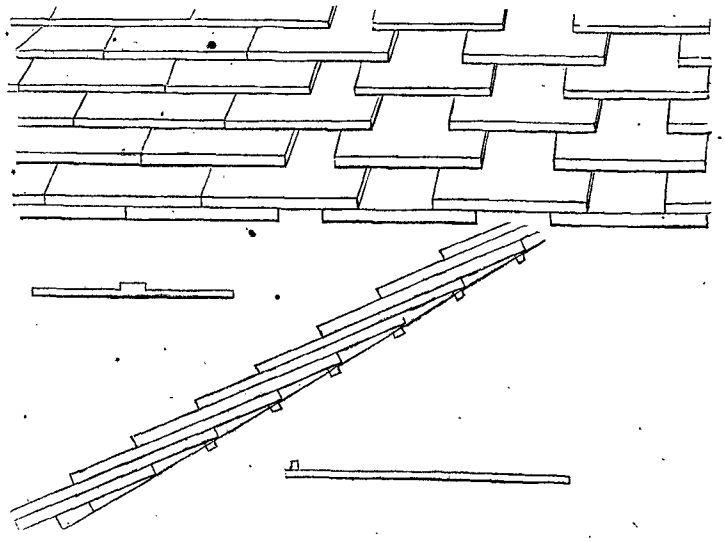


Fig. 602. FLAT TILES LAID SIDE BY SIDE.

and those which present a convex back, and form the outer surface of the roof, abut against a cylindrical tile which covers the joint.

The Flat Tiles, one edge of which has a fillet, and the other a semicircular turn, seem to combine the use of the two tiles in the former example, and to produce a much better

effect; they are more in accordance with the ancients; by forming them in such a manner that the ribs become portions of cones, they will fit each other and make a very strong covering.

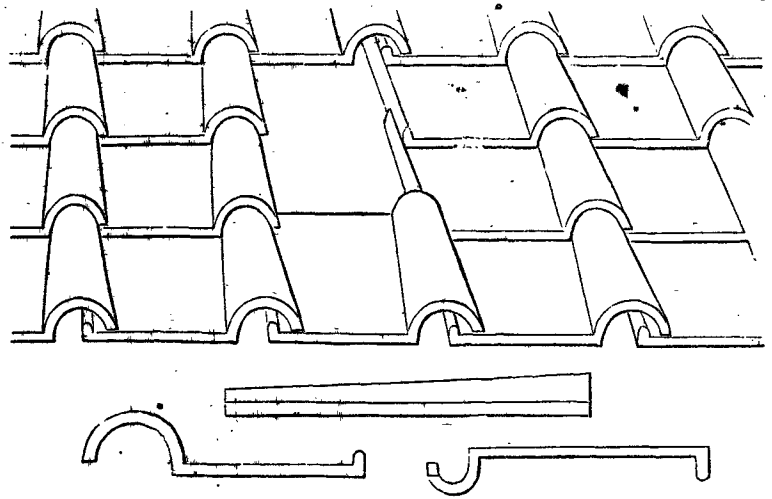


Fig. 603. TILES IN IMITATION OF THE ANTIQUE.

Numerous other specimens might be given of the ornamental tile: among them the following show the great variety of pattern that may be produced; and it is to be regretted

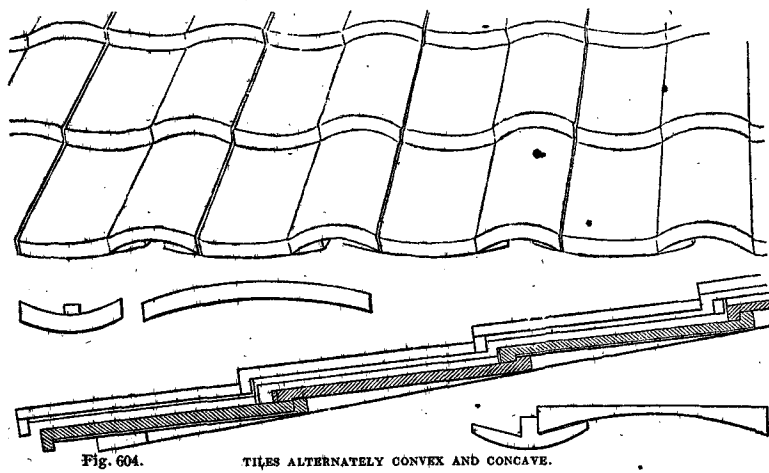


Fig. 604. TILES ALTERNATELY CONVEX AND CONCAVE.

that the covering of our buildings should continue to exhibit the monotonous plain and pantile, when so many picturesque designs might be substituted for them.

To tiles as a covering for a roof there are some objections, and generally slate is now preferred; but their manufacture is capable of great improvement, and when their surfaces are glazed, so as to render them impervious to wet, they are upon an equality with slate. Tiles, in the ordinary state, when exposed to moisture or to rain, will imbibe about a seventh of its weight of water, while slate, if of a good quality, will not take up more than a two-hundredth part: if tiles remain saturated with water for any length of time, they certainly injure the timber on which they are laid, and will probably occasion the rooms constructed in the roof to be affected by damp.

Pavements are frequently formed of glazed tiles; those in imitation of the ancient tesseræ have a good effect: in the middle ages our churches were paved with a square tile, each of which had a different pattern, or formed figures and devices resembling those of a carpet.

CHAP. V.

MORTAR AND CEMENTS.

CALCAREOUS mortars and cements are said to acquire their hardness by the slow absorption of carbonic acid from the atmosphere, though few mortars that have been submitted to the process of analysis have exhibited the quantity of acid necessary for the full saturation of the lime, every 28 parts by weight requiring 22 of carbonic acid. This idea was probably suggested by noticing that the outer surface of a lump of mortar first exhibited the greatest hardness, and then the portion nearest to it, and at last the centre. According to one theory a chemical affinity exists among the ingredients that compose the mortar, so that the lime acting upon the alumina and sand or silica enters into combination with them; while another supposes that the particles are only affected by mechanical agency, and that the lime adds to their cohesive properties. The minute state of the lime, and its extreme division, allows it to spread over the entire surface of the particles of sand, bringing them more closely into contact, or it fills up their interstitial spaces, forming a matrix to hold them together.

Lime is superior in its adhesive power to that of its cohesive, and therefore attaches itself to hard bodies in preference to its own softer particles. The hydrates of lime and alumina, when powdered and mixed with water, possess great adhesive powers, which is not the case with anhydrous substances, as carbon and silica: those bodies which harden quickest have the strongest affinity for water, though some substances which will not harden in this liquid will in others. Lime-paste slowly dried acquires considerable cohesive properties: rich limes, when mixed with sand or grains of silex to form ordinary mortar, being very soluble in water, remain in a soft state when excluded from the air for a length of time; but when a small portion of puzzolana is added in a finely comminuted state, the lime loses its solubility, and in a short time hardens under water, probably occasioned by a chemical combination taking place between the lime and puzzolana.

Hydraulic Mortars are composed of silica and caustic lime in general, and their peculiar property may be attributed to their forming a hydrated silicate of lime; when clay and magnesia are added, double silicates of greater consistency and strength are produced: the silica should always be in such a state that it is easily converted into a gelatinous paste by the addition of an acid, and should be prepared by calcining it with an alkaline earth at a bright red heat, after which it will dissolve in acids. Sand of the quartzose kind, when mixed with lime in the ordinary way, will not form hydraulic mortar; but if after, when reduced to fine grains, it be burnt with the lime, it becomes suitable for the purpose of building in water: those limestones which contain 10 per cent. of clay, when strongly burnt, form good hydraulic mortars; but if this proportion be increased to double or more, it requires to be well ground before it will set. Marls which contain 30 per cent. of clay make an excellent mortar without adding any other ingredient; when the proportion of clay is greater, it must not be subjected to any great or prolonged heat; if strongly calcined it becomes vitrefied, and requires pounding, or grinding very fine, as well as an addition of some strong lime to make an hydraulic mortar. When 1 part of silica and 4 of caustic potassa are fused together and slowly cooled, a part of the compound may be poured out of the crucible before the whole has solidified, and pearly crystals are formed in the residuary portion, composed of 1 atom of silica and 1 of potassa: when 1 part of silica and 2½ of carbonate of potassa are fused together, the carbonic acid is expelled, and a bisilicate of potassa is formed; these silicates are soluble in water; this solution may be also obtained by digesting gelatinous hydrate of silica, or very finely divided silica, in solution of potassa.

In Holland a substance called terras or trass has been from time immemorial used as a water cement; it consists of a substance called *Wakke*, a species of basalt, and has been employed in forming mounds or barriers against the irruption of the sea: according to Morveau compact basalt, after burning, made a similar cement to the Dutch terras; and a material very nearly resembling it is found in great abundance near the port of Leith, and in the vicinity of Edinburgh.

The Mortar made use of by the Egyptians was formed of sand and lime, nearly in the proportions we now adopt: 100 grains taken from the pyramid of Cheops were carefully analysed; after being reduced to a fine powder, dried thoroughly, and immersed in 6 ounces of pure water for some time, they were heated to remove the soluble salts: when filtered after this operation the mortar was found to have lost 18¾ grains, which consisted of 15·3 sulphate of lime, and 3·2 of soda. The residue of 81¼ grains had 4 cubic inches of dilute

muriatic acid poured upon them, and there was then a loss of 4·7 grains of carbonic acid, the total weight of which in the mortar was 5·64 grains; and on completing the process the constituents were found to be

	Grains.
Sulphate of lime and soda	18·5
Carbonic acid	5·64
Lime	10·7
Alumina	0·3
Alumina and crystals of selenite	54·7
Water and loss	10·16
	100·00

This mortar does not appear to contain any siliceous matter, and is a compound of rich lime and coarsely powdered gypsum, as a substitute for sand, in the proportion by weight of 1 of lime to 5 of gypsum: it possessed considerable tenacity, and its specific gravity was about 1·98.

The Greeks used a fine mortar, and well understood the composition of stuccoes; some that remain at the present day cannot be surpassed for whiteness, hardness, or polish: their floors were made of a cement resembling the finest marble, which dried so rapidly after washing, that there was no danger of any injurious effects, even when walked on without the sandal.

The Romans, according to Vitruvius, paid great attention to the selection of their limes, and considered that of the finest quality which was made from the hardest and purest marble: for hydraulic purposes they generally made use of puzzolana, being perfectly aware that common lime and sand would not set under water: all Roman mortars exposed to the action of the atmosphere seem to be alike; they are composed of pounded tile or brick, coarse sand or gravel, and lime, the latter often occurring in small lumps, as if not properly slaked: their artificial hydraulic mortars were composed of pure lime and large proportions of pounded brick, which, when broken, resemble a brescia of which lime is the matrix: with this they lined their reservoirs, first preparing it by beating, and floated it on the walls by means of sandstones, which they rubbed over the surface; upon this was laid a fine coat of plaster, and then one of red lead and oil; the first rough coating dried the plaster rapidly, by absorbing its superabundant water. These cements or mortars very frequently exhibit on their surface a coating of carbonate of lime, particularly in the conduits of the aqueducts, some of which are extremely hard, and of considerable thickness. We have many remains of limestone quarries worked by the Romans; one, called Calcariæ in the Roman Itineraries, is situated at Tadcaster in Yorkshire.

Lime is the essential ingredient of all calcareous cements, and is never found in a natural state quite pure; it is usually that of an earthy salt, which crystallised is called calcareous spar; when massive, limestone is found combined with carbonic acid in the proportions of 46 to 54 of lime. This gas, which is sparingly soluble in water, is a permanently elastic fluid under the ordinary pressure and temperature of the atmosphere. The whitest limestones, as the white granular marble, for instance, are nearly pure, only containing a small quantity of siliceous earth; this, when subjected to calcination, falls into a coarse powder, and, as it cannot be burnt in an ordinary kiln, is not in use for the purpose of making mortar.

Chalk, in consequence of its requiring less fuel to convert it into lime, is preferred; but as it is subject to be only superficially burnt, and to contain, in consequence, a quantity of core, it is not so eligible for the builder.

Oolite Limestone is the next in quality, and superior to this is the grey limestone, which requires longer time, as well as more fuel to convert it. The swinestones and bituminous limestones, which are of a dark brown colour, become frequently black when heated red-hot, the carbonic acid is converted into carbonic oxide, which, having no attraction for lime, flies off, leaving the lime perfectly white, very caustic, and more porous than that produced from the compact limestones; this kind, when exposed to air, or the action of water, crumbles into a fine powder, and is useful for mortar.

The Magnesian Limestone is found in the new red sandstone formation in thick beds, either of a reddish or yellowish tinge; they are compounds of carbonates of lime and magnesia, in the proportions probably of three-fifths of carbonate of lime and two-fifths of the carbonate of magnesia: after burning it retains its causticity for a long time.

Grey Chalk or Chalk Marl, which contains a large proportion of iron and clay, formed the bottom bed of the great chalk deposit, and contains no flints; that which is used for hydraulic mortar has from 10 to 25 per cent. of clay, and when burnt has a pale yellow colour.

The blue limestone, or the dark dove colour, when burnt into lime, becomes buff; it is found both in the transition and mountain limestone deposits, and constitutes nearly the whole of the lias formation: its position is between the lower oolite and the new red sandstone, and its entire thickness is 250 feet. Watchet, Aberthaw, and Barrow in

Leicestershire, are all on the same bed, and Smeaton found, upon a careful analysis, that the proportions of iron and clay in each were the same, or about 11 or 12 per cent.

For the Eddystone lighthouse he used equal measures of Aberthaw lime, in the state of hydrate, and of fine powdered puzzolana, proportions which when reduced to weight, and allowing 24 per cent. for water, agree with those stated by Vitruvius to be in use among the Romans. The Dorking lime is used for land and water cements, as is the Merstham, both of which are obtained from the chalk marl, as is the Halling on the Medway.

In the cements made from lias the oxide of iron they contain appears to combine with the lime during the process of burning, and sets without difficulty when mixed with a large proportion of sand.

The Tournay mortar is a lias cement, and thus formed: after the lumps of lias are withdrawn from the kiln, what remains with the ashes of the slaty coal, in the proportion of three of ashes and one of lime, is sprinkled with water, just sufficient to slack the lime. It is then beaten by an iron pestle for half an hour; this is repeated three or four times, until it attains the consistence of mortar. It is then placed under cover, and in a few days beaten again, either with stone or brick; it acquires in a short time great hardness. The coal ash in this instance is burnt clay in a state of fine division, and therefore ready to combine rapidly with the argillo-ferruginous lime, which, being in a state of hydrate, and allowed to be some time in contact with the ash, a combination takes place, which is further increased by beating, the lime parting with its water, and combining with the ash.

As it is of the utmost importance to understand the nature of the hydraulic limestones, M. Berthier recommends the following method of analysis: after the specimen has been reduced to a fine powder, it is passed through a hair-sieve, and a given quantity is put into a vessel; muriatic or nitric acid, diluted with a small quantity of water, is poured upon it, taking care to stir the whole with a glass or wooden rod. When the effervescence has begun, the solution is to be evaporated by a gentle heat, until the whole becomes a thick paste; this is put again into a small quantity of water, and filtered; all the clay contained in the paste will remain in the filter, and the substance which has passed through must be dried in the sun or by the fire, and afterwards weighed: or the specimen to be examined may be calcined to redness in an earthenware or metal crucible, and very clear water being poured into the solution, a precipitate will be formed, which is magnesia; this, washed in pure water, and dried speedily, is to be then weighed. The clay may be thus estimated, as well as any fine sand that it may contain.

The only apparent difference between lime obtained from limestones and chalk is that of the greater retention or expulsion of the carbonic acid gas, and both Smeaton and Higgins have proved that when chalk or stone lime is equally fresh from the kiln, their qualities as cements are nearly equal; but as chalk lime absorbs carbonic acid more rapidly from its spongy texture, it loses much of its cementing quality, and does not make so good mortar as the lime from stone.

Limestones are sometimes found wholly composed of lime and carbonic acid: the best hydraulic limestones contain silica, alumina, magnesia, iron, and manganese; the silica being the most abundant.

The rich or fat Limes are those which in slaking double their volume, and after having been immersed for a length of time retain their consistency, and in pure water will dissolve to the last particle; they are derived from the pure limestones, which contain from 0·1 to 0·6 of silica, alumina, magnesia, and iron; they absorb in slacking nearly 300 per cent. of their weight of water.

The poor Limes do not much augment their volume, and only partly dissolve, leaving a residue, which has little or no consistency; they are produced from the limestone in which silica is present in the state of sand, magnesia, the oxides of iron and manganese, and absorb about 200 per cent. of water.

The moderately hydraulic Limes set in 15 or 20 days after they are immersed, and then continue to become harder in quality; at the end of a twelvemonth they acquire the consistence of soap, in pure water dissolve with difficulty, and expand in slaking.

From Limestone, united with Clay, Magnesia, Iron, and Manganese, in the proportion of not more than 15 or 18 parts out of 100 of the whole, are obtained the hydraulic limes; these set after six or seven days' immersion, and continue to acquire hardness; such lime absorbs, on slacking, 250 per cent. of its weight in water. Some of the best hydraulic limes are obtained from limestones which have, in addition, a greater amount of silica, or where it occupies nearly half the whole quantity of the other substances; these kinds set on the second or third day after immersion, and in a month become hard and perfectly insoluble. Lime is said to set when it will bear without depression a rod the twentieth part of an inch in diameter, loaded with a weight of 10 or 11 ounces avoirdupois, or when it will resist any indentation made by the finger moderately pressed.

By these observations it would seem that there are no definite proportions between the quantities of silica and alumina or of magnesia which unites with the calcareous matter; but it is well ascertained that no good hydraulic mortar can be made without

silica, and that the best limestone for the purpose is that which contains a certain quantity, with alumina in the proportions usually found in clay. Limestones are made into lime by driving off the carbonic acid and water by burning them in open kilns.

When limestone is in a pure state it will bear a white heat, but that which contains the properties to render it an useful hydraulic lime easily fuses; its calcination, therefore, requires more care; the heat should never exceed redness, and the burning should not proceed too rapidly; if exposed to too great a heat, they become covered with an enamel, and the carbonic acid is not driven off, and consequently they will not slack. The forms of kilns used for this purpose vary in different districts, as they are cylindrical, conical, egg-shaped, or prismatic.

Flare Kilns, intended for burning scares or faggots, have the limestone, with which they are fed, resting on one or two vaults, built up dry with the materials of the charge: a small fire is lighted beneath the vaults or arches, and this is gradually increased, as the draught gains strength. The air which rushes constantly through the flame passes through the charge, and by degrees renders the whole of the mass incandescent: the lime required for this kind of burning varies according to the size and quality of wood used.

Vicat, who made many experiments upon lime and mortars, ascertained that if lime was plunged into water for a few seconds, and then withdrawn, it decrepitated and fell into a fine powder, which might be kept in a dry place for a considerable time, and would not again heat when water was added to it.

When lime was slacked in the common manner 100 parts by weight of common fat or rich lime absorbed 236 per cent. of its weight of water, and its volume was increased to 310; when slacked by plunging for a few seconds, it absorbed 131 per cent. of water, and its bulk increased to 104; and when slacked by mere exposure to the air, it absorbed 148 per cent. of water, and its volume was augmented to 176. The same lime, therefore, will produce cream of lime of the same consistence, with different portions of water as either of the above processes are adopted.

The great quantity of water absorbed by the common process shows us that the particles of lime are minutely subdivided, and, therefore, in a state to take up a greater quantity of sand.

The quantity of water absorbed by the hydrate of lime has a material influence on its hardness. One hundred parts of rich lime, by weight, imbibing 137 parts by weight of water, acquired a hardness of ·126; of 183 parts, ·222; and when 315 parts, by weight, ·068, so that the middle quantity gave the best result. The greatest tenacity in the common limes was obtained by the usual method of slaking, the next by spontaneous evaporation, and the least by immersion. The greatest tenacity of the hydraulic limes is also found to be in the same order.

Water has no action on the hydrates of the hydraulic lime, but it dissolves and decomposes the rich lime; the latter, if slacked and made into balls and then exposed to the air, will in a month or two be covered with a carbonate of lime; if these balls are then broken and plunged into water the interior lime will dissolve, and the shell or carbonate will remain. The solidification of common mortar is therefore accounted for by the reformation of a carbonate of lime, the hydrate of lime attracting carbonic acid from the atmosphere: the water which holds the lime in solution for any length of time combines with the carbonic acid, and as evaporation proceeds slowly crystallisation takes place; this, according to some opinions, constitutes the hardness of old mortar.

Where coal is used the limestone and coal are indiscriminately mixed, the quantity of the latter varying with the hardness of the limestone to be reduced: 1 bushel of coal will make 4 or 5 bushels of lime, the magnesian limestone requiring still less. Where there is any aluminous earth in the limestone, the fire must be kept down by means of a damper introduced in the kiln, or there will be danger of the lime becoming vitrefied in consequence of its affinity for silex and alumina: a white heat will often convert lime into glass; good lime may be made with a slow red heat.

Common lime, when slacked under water, takes up more than it can solidify, and, as it cannot then throw off the superfluous quantity, remains in a state of paste: hydraulic limes, on the contrary, when slacked, and brought to the consistence of cream, if plunged into water, in setting give up the superfluous quantity, and if made into a thick paste before immersion, then absorb sufficient to set them. The hydraulic limes, when mixed with sand, make an excellent mortar for buildings that are out of the water, and the richest, which take up a greater quantity of sand, would be found the most economical for general purposes.

When Limestone is to be converted into lime, it is not unusual to sprinkle it with water before it is thrown into the kiln, which aids the process. The carbonate of lime, if heated too violently, and in a close vessel, melts and crystallises again into a state of carbonate; when it contains any mixture of alumina, and is burnt in contact with charcoal, it is not so well adapted for hydraulic mortar as when burnt with coal. The best fuel is the *blaze* from wood or furze, for it has been found that charcoal has the effect of depriving it of

the strength which it acquires from the flare or flame heat: pure lime and clay thus heated in a kiln will produce good hydraulic lime.

When water is thrown upon a subcarbonate, however, it will form a hydrocarbonate, which will not set under water, and with an excess of base is more difficult to reduce into lime than a neutral carbonate by a second calcination; this will in some degree account for the difficulty of converting limestone into lime, when it has been chilled before calcination is complete.

Artificial hydraulic lime, which is so necessary for all engineering works, is now generally prepared by mixing with a rich lime a certain proportion of alumina or clay, and then subjecting it to the process of calcination: with lime so prepared the beton, a mass composed of hydraulic lime and rubble, is made, the lime being slacked previous to its mixture; this sets under water, and is universally employed in France, where the piers of bridges are founded on a beton composed of sand, flint, and artificial hydraulic lime; it is often applied at great depths in a caissoon without a bottom, and after it has been deposited 8 months, has been found hard enough to bear 2500 tons on a surface of less than 100 square yards. Chalk is sometimes used, which being quickly reduced to a powder is formed into a paste by the addition of water, but does not produce so good an artificial lime, in consequence perhaps of the less perfect state of the combination of the materials. Calcareous substances cannot, without slaking or subjecting them to heat, be reduced to the same state of fineness. The proportion of lime and clay for the manufacture of hydraulic lime must vary according to their quality; but 20 parts of dry clay added to 80 of rich unslacked lime, or 140 of carbonate of lime, is found to be a good proportion; the finest and softest clays are always preferred.

Parker's cement was first patented in 1796: it contains 45 per cent. of clay, and 55 of carbonate of lime, according to Sir Humphry Davy, and the mineral substance used for its manufacture is a reniform limestone, found in nodules in beds of clay; they are most abundant in the argillaceous strata, which alternate with those of oolite, and the clay stratum, which reposes on the chalk and often on the London clay. In Kent they are found on the coast of the Isle of Sheppey, and are called *Septaria;* the siliceous clay of which they are composed contains veins of calcspar; after these *Septaria* or cement-stones are collected, they are subjected to calcination in kilns, and the cement is packed in casks; their analysis shows usually 55 parts of lime, 38 of alumina, and 7 of oxide of iron.

In Yorkshire there is a cement made for hydraulic purposes, which contains 34 parts of clay, and 62 of the carbonate of lime, and that obtained at Harwich, which sets very quickly, has 47 parts of clay, and 49 of carbonate of lime.

When this material is properly burnt it is of a light brown colour; the cement, when taken from the kiln, requires grinding before it is fit for use, and when mixed with water it regains all the carbonic acid that was driven off by burning. The stone or septaria of which this invaluable cement is made is fine grained, and susceptible of polish, its specific gravity being about 2·59.

Its components after a careful analysis are found to be,

Carbonate of lime	-	657
——— of magnesia	-	5
——— of iron	-	90
——— of manganese	-	19
Clay - { silica	-	180
Clay - { alumina	-	66
Water	-	13
		1000

Two measures of sand and one of good cement powder form an excellent composition for ordinary building purposes, though many prefer equal measures of each; cement, however, unites more readily and powerfully with brick or stones when it is perfectly pure and unmixed with sand: for the lining of reservoirs or cisterns it is used pure, and if mixed with sand is seldom found to be water-tight; hence where a thickness is required, it is better to dub out with tiles as much as is necessary, using only pure cement.

Kilns for burning Parker's Cement. — That in Her Majesty's dockyard at Sheerness is circular, 17 feet in diameter from out to out, and about 21 feet 6 inches in height: an inverted cone occupies the middle, which has a clear diameter at top of 8 feet, and at bottom of 5 feet 6 inches, where there is a conical mass of brickwork, which spreads the cement as it falls through the ash-holes or eyes; there are four of these placed at regular distances, each 30 inches in width, and 18 inches in height, to the crown of the flat arch that covers them; within are fire-holes a foot square, which have iron bars to support the brickwork above them. Around the entire cylindrical kiln are four wrought-iron hoops $\frac{3}{8}$ of an inch in thickness, and 3 inches in width, for the purpose of holding the work

together: these are placed at regular distances from above the lower arches to the top, and are held by vertical iron bolts where they join: the kiln will hold a charge of 30 tons of broken cement-stones measuring 26 cubic feet to the ton, as well as the fuel required for burning it. When used the bottom is covered with wood, and the coals and cement-stones are arranged in alternate layers, each about a foot in thickness: after it has been lighted three days the lower part may be drawn, and then by constantly filling up, this may be done every twenty-four hours: the cement-stones and coals are thrown in from the top, and every ton of cement-stone yields 21 bushels of cement powder. In the mill for grinding this cement, the materials are thrown by a labourer into a sieve containing seventeen wires to an inch, which is shaken by the machinery attached to the steam-engine, after which it is packed into casks and kept ready for use: two tons of cement powder are ground during the day.

In France the materials selected for the manufacture of hydraulic mortar are the chalk of the country, and a clay which contains 63 parts of silica, 28 of alumina, and 7 of oxide of iron; after they are reduced into small lumps they are ground in a mill, the stones are placed on their edges, and followed by a strong wheel to which is attached a set of rakes; these are moved by a 2 horse-wheel in a circular basin 13 feet in diameter; in the middle is the pivot of the vertical axle which supports the machinery: water is allowed to flow into this basin as required, and the proportions of chalk are three measures to one of clay. When this has been subjected to the action of the mill for an hour and a half, it is drawn out in the state of a thin pulp into four or five successive reservoirs, in the last of which it stands until it has obtained its requisite consistency; the mass is then cut out into prisms, which are placed on shelves to dry, and in a short time they are sufficiently so to be subjected to the process of calcination.

Smeaton's observations on water cements show that the quality of lime does not depend either upon its hardness or its colour, for the white lias of Somersetshire, though approaching to a flinty hardness, and having a chalky appearance, he says, is not equal to the clunch lime, obtained near Lewes in Sussex, which is of great repute for all works executed in water. This clunch lime is a species of chalk, not found, like the lias, in thin strata, but in thick masses. It is considerably harder and heavier than common chalk, but yet of the lowest degree of what may be termed stony hardness, and inclining to a yellowish ash colour. When analysed, it contains three parts out of sixteen of its weight of yellowish clay, with a small quantity of sand, seemingly of the crystal kind, not quite transparent, but mixed with red spots: hence the fitness of lime for water building seems neither to depend upon the hardness of the stone, the thickness of the stratum, nor the bed or matrix in which it is found, but in burning and falling down into a powder of a buff-coloured tinge, and in containing a considerable quantity of clay; and he found all the water limes to agree in these particulars, among which that obtained at Dorking, he supposed, was stronger than that made from common chalk, it containing one-seventeenth part of light-coloured clay of a yellowish tinge.

Sutton lime in Lancashire, he observed, had this buff cast, the stone itself being of a deep brown colour, its quality as a water lime not depending upon its colour before it is burnt: this limestone was found to contain three parts out of sixteen of its weight of brown or red clay, and one part out of forty-two of fine brown sand, making a lime very superior to all others for water-building.

The mortar used at the Eddystone lighthouse was composed of equal measures of puzzolana and blue lias lime, slaked into a powder, forming a very strong cement, and setting well under water, though requiring considerable time to do so: in this sand was altogether omitted, and when two bushels of slaked lime powder were added to two bushels of puzzolana, the whole occupied 2·32 cube feet. For the common face mortar, to two bushels of lime powder were added one bushel of puzzolana and three bushels of common sand, which occupied 4·67 cubic feet.

Smeaton also used a water-lime and minion, or siftings of the ironstone, after calcination at the iron furnaces, which were ground in a mill before being added to the powdered lime; this minion or forged scales, he considered, when well pulverised, and sifted clean from dirt and glassy slag, equivalent to as much puzzolana or tarras. Two bushels of lime, two bushels of minion, and one of sand was the proportion for face mortar; and for backing mortar, two of lime, ½ bushel of minion, and three bushels of common sand, occupying 4·17 cubic feet.

When common lime was mixed with minion for ordinary face mortar he employed two bushels of lime, the same quantity of minion, and two bushels of sand, making 4·75 cubic feet, and for common lime, mixed with tarras, his proportions were for tarras mortar two bushels of powdered lime, and one of tarras or 1·67 cubic feet; and for the backing mortar, to the same quantity of powdered lime, only ½ bushel of tarras, and three bushels of sand, or 3·50 cubic feet.

Puzzolana, obtained near Naples, is of a violet red colour, and of volcanic origin: it is sometimes found in coarse grains in slag, pumice, or tufa, and often of a yellow, grey, or

black colour: it is composed of silica and alumina, with a small quantity of other matters; a portion analysed by M. Berthier contained silica 44·5, alumina 15, lime 8·8, magnesia 4·7, oxide of iron 12, soda 4, potash 1·4, water 9·2, in 100 parts, and the only preparation to which it was subjected was grinding and sifting; when reduced to a fine powder, it is beaten with a due proportion of lime to a proper consistency.

Puzzolana was obtained by the Romans near Baiæ, and, mixed with lime and small stones, Vitruvius tells us it acquired great hardness from the moisture it absorbed, and that it would resist the dashing of the waves and the action of sea-water. Acids will, however, act upon it, though some specimens are not at all affected by them; others, when washed with sulphuric acid, become covered with an aluminous efflorescence; puzzolana thrown into limpid lime-water decomposes it more or less, but a sufficient quantity restores it to a state of purity.

We find the mortars or cements used by the Romans in this island composed of chalk lime, sand, pounded brick or tile dust, occasionally mixed with ashes of wood or charcoal, the residue of the hearth where the lime was burnt, and the carbonic acid of the chalk driven off; their mortar is remarkably hard, generally of a pinkish tint, and often when broken exhibits cavities which contain crystals of the carbonate of lime. This kind of mortar is perhaps the most ancient of the artificial puzzolanas known, and we find it throughout Europe in every place occupied by the Romans; its weight and durability have occasioned it to be considered as more excellent in quality than that made at the present day; but this apparent advantage is entirely owing to time, which has permitted it to absorb from the atmosphere a greater quantity of carbonic acid, and to become in consequence more solid, and capable of bearing greater weight.

Numerous experiments were made during the last century by the French chemists upon the ochreous clays, in order to form a substance that would answer the same purpose as the Italian puzzolanas; and M. Bruyere has shown us that by a mixture of powdered clay and lime, in the proportion of three of the first to one of the latter, an active cement is formed, which sets under water in a few hours, but never arrives at a very great degree of hardness: all kinds of clay composed of silica and alumina, and a little oxide of iron, and no carbonate of lime, if soft and fine in their textures, will produce, by proper treatment, a very active and energetic puzzolana.

A clay which does not effervesce in nitric acid, and when burnt has a brick-red colour, if after it is pulverised, it is thinly spread in a layer on a plate of iron, and heated to redness, allowed to remain about twenty minutes, taking care continually to stir or move it with a rod, so that all the particles may be properly and thoroughly calcined, forms an excellent artificial puzzolana, which, mixed into a stiff paste with half its weight of lime, becomes very hard in water.

Pipe clay, which contains a considerable quantity of silica, but no carbonate of lime, after burning, will set, with the same proportion of lime as in the preceding example, into a very hard cement, after it has been immersed five or six months.

Clay calcined at too great an heat loses its quality as a puzzolana, and it never should be so great as is required to burn a sound brick; the artificial puzzolanas, made by the ancients by pulverising old tiles, bricks, and the residue of their potteries, shows us that those materials in which there had been a deficiency of burning were employed in preference.

Sand varies in the size of its particles, and where rubble-work is employed, after the coarse stones are filled in with the finer sorts, the interstices are run in with some cementing substance; to estimate the exact amount of all these spaces, a measure is made of each of the varieties, and afterwards of the quantity of water to fill them up. In pebbles of about half an inch in diameter, the void is equal to half the measure which contains them; in gravels, five-twelfths; common sand, two-fifths; fine sand, one-third; and very fine sand, two-sevenths.

To ascertain what proportion of each, when mixed, would approximate a solid mass, or fill up all the voids, requires more consideration, though this is commonly done by first filling a measure with the larger stones, and then by degrees adding the finer; and when all in the proportions of their bulk have been calculated, they may be put together, and if the measure, when duly shaken, is no more than full, we are sure the interstices are filled up.

The sand usually preferred for making mortar has a sharp grit, and is obtained from rivers; the proportions with which it is compounded with the lime varies in different districts according to the quality. Mortar for ordinary constructions is composed of one part of stone lime and three of sand mixed together; the lime, being in a perfectly dry state, is thrown into a basin formed by heaping up the sand around it; water is then sprinkled or thrown on to slack the lime, and it is immediately covered over with sand; after remaining some time in this state, and the whole of the lime has been reduced to powder, it is turned together, then passed through a wire screen, where all the core, or that portion of the lime which has not slaked, is taken out. The whole has then more water poured upon it, and being triturated or larryed, is rendered fit for the workman.

The lime is sometimes placed in the middle of a heap of sand, and after water has been thrown on it, it is amalgamated together by hoes; after remaining in this state a few hours, it sets and is fit for use: by this means the lime takes up a larger quantity of sand; 72 bushels of good stone lime, and 18 yards of sand, when formed into mortar will have a cubical content of 315 feet.

Sand is the produce of the spontaneous disintegration of the granitic, schistose, or calcareous rocks, and their specific gravity is the same as that of quartz, a cubic foot of which would weigh 162½ pounds, but when in the state of sand it does not weigh more than 75 pounds, so that the interstitial parts are more than equal to the sand itself: the proportion of lime to fill up these spaces between the particles of sand must be ascertained before we can have a solid mass, and the difference between the weight in its loose and compact state ought to give us the quantity of lime requisite to bind the particles firmly together.

Concrete is of very ancient use, and formed the foundations as well as hearting of the walls in the remotest ages, and among all nations: it is made by mixing lime, coarse gravel and sand together, with a moderate quantity of water. The lime should be reduced to the state of a fine powder, which is done immediately it is brought from the kiln, by grinding it in a mill, or by pounding it; when used it is slaked and not before, the ordinary method employed is to mix it with the other ingredients as quickly as possible, and then add the water immediately before it is put into the barrow and wheeled to its destination, or where it is to be thrown down.

Neither gravel nor sand alone will form a perfect concrete, for when large pebbles are mixed with quicklime and water, they are not in any way held or cemented together, but when fine sand is used in the ordinary proportions of common mortar a concrete is formed; and a mixture of coarse with the fine sand renders the mass still more compact: when all the materials are properly mixed together, the lime combines with the fine sand only, and cements the pebbles or larger stones together, forming a rubble, so that the proportions of sand ought to be precisely those required to make mortar of the best quality.

In the sea wall at Brighton the proportions were six parts of large shingle and well-sifted sand, and one part of grey chalk lime fresh from the kiln; these were not mixed together at one time, but three parts of sand and one part of lime were first made into mortar of the ordinary kind, which was thrown with an equal quantity of beach shingle into a pug-mill, where they were well mixed together before being used.

Artificial stone has been formed of concrete, and the process patented by Mr. Ranger; the moulds have at the bottom a flat board, made larger than the size of the intended stone to be cast; the four sides are held together by iron cramps, tightened up by means of wedges: when the moulds are prepared they are laid out to receive the mixture of gravel, sand, quicklime, and boiling water, which is thrown into them as rapidly as possible, and kept constantly rammed down until the mould is full; the surface is then floated over with mortar and rendered quite smooth.

Boiling water has the advantage of causing the lime to slack more rapidly, and therefore fewer moulds are required; in half an hour these artificial stones are sufficiently set to allow of the moulds being taken to pieces, after the trenails are drawn which kept the sides together; two holes are left in the concrete block to attach any tackle that may be required to hoist them to their destined position: when the boards which form the mould are all withdrawn, the blocks are put up to acquire hardness, which they do in two or three months.

Whenever concrete is used for the foundation of a building, it should be thrown from as great a height as possible, which compresses it into a more solid mass: its depth when laid in trenches, or spread over an entire surface, should never be less than 4 or 5 feet, and where great weights are to be borne not less than 6 feet.

The hydraulic mortar in the construction of the Menai Bridge in North Wales, made of Aberthaw lime and sand, was found to answer admirably well; it was composed of one measure of lime to two of sand; that used by Perronet at the bridge of Neuilly in France had equal measures of lime and pounded tile from the Neuilly kilns, ground very fine.

The artificial hydraulic lime made by Guyton de Morveau at Lena, in Sweden, consisted, according to Bergman, of ninety parts of carbonate of lime, six of clay, and four of oxide of manganese.

General Treussart's system for making artificial puzzolana is, first to reduce soft red bricks to powder and mix them with common lime which has been some time slaked, in the proportion of two measures of brick-dust to one of lime paste, with the addition of as much water as is necessary to incorporate them thoroughly. Common lime, sand, and brick-dust in equal quantities he also found to make a good hydraulic mortar: he observes that all hydraulic limes set much quicker in summer than in winter, and may be considered good when either as hydrates, or mixed with sand, they set in the course of eight or ten days in the summer, and acquire a hardness sufficient to resist the pressure of the finger.

CHAP. VI.

OF PISÉ.

THIS method of construction is far more simple than that where unburnt bricks are employed, and by no means so costly; it is universally adopted in the departments of the Ain, Rhone, and Isère, in France, and forms fire-proof houses, far preferable for cottages to timber framing, and well suited for barns, stables, or sheds attached to a farm.

Walls properly carried up in this material form one entire mass, and covered with a fine coat of plaster will endure for ages, and present an agreeable appearance. Rondelet informs us that he repaired, in 1764, an ancient chateau in the department of Ain, which had endured for upwards of 500 years, and that the walls had attained a hardness and compactness equal to ordinary stone; when desired to increase the size of the windows and other apertures, the workmen were obliged absolutely to use the same tools as in a quarry.

The Romans practised this system at a very early period in Gaul, and we find mention made of it by Pliny, who in admiration observes: "What shall we say, do we not see in Africa and in Spain walls of earth called *formacei*, having the form given to them by planks and boards placed on each face: and between which prepared earth has been rammed? The earth so rammed, I can assure you, does continue for years in an imperishable state, and is neither affected by the beating rain, by wind, nor by fire, and neither mortar nor cement is used in them. In various parts of Spain we see the high watch-towers built by Hannibal, upon the summits of mountains, with this material."—Pliny, lib. 35. cap. 14.

Manner of making Pisé.—The ants probably suggested the process of preparing earth for building purposes, and in the tropical climates we discover these industrious insects almost rivalling man in the arrangement and strength of their habitations: the elevation of their houses exceeds in height 500 times that of the builders. The termites, which are scarcely a quarter of an inch in size, pile up dwellings 7 feet high, and sometimes as much as 20. Bishop Heber describes some in India which were as much as 7 or 8 feet in circumference; within were numerous galleries and cells, the principal of which was occupied by the king and queen, placed nearly in the centre; its floor was more than 1 inch in thickness, formed of clay, and the roof one solid well-turned oval arch of considerable strength.

The Termes mordax and Atrox, or turret-building ants, form their habitations with a well-tempered black earth, often 3 feet in height, in form of a conical mushroom: all the varieties of ants select a fine clay for their cells, galleries, and bridges; lining their rooms with a composition formed of wood and gum, which these insects seem to have the instinct to prepare in a very fine state, and to lay on like a coat of cement: thus it is that man may receive instruction from a close observation of the habits of the animal creation. All earth is suited for pisé-work, but the best is clay which contains small gravel, and of such a consistence that it can be dug with the common spade: every kind of earth that will sustain itself, with a small slope, is adapted for the purpose, and may be successfully used. To prepare it, after beating thoroughly, it must be passed through a screen to take away the stones beyond the size of a common hazel nut; and if not moist it must be watered, and turned over with a shovel until it has acquired a regular consistence, which is known by moulding it by the hand, or between the fingers, and then throwing it into a vessel, when, if it retains the shape given to it, it may be considered as fit for use. After the earth is thus prepared, it is put into a frame or moveable box, where it is forced down and beaten with a rammer. There is some attention necessary for the construction of this box, which is formed of deal planks put together, with their joints ploughed and tongued, and further strengthened with clamps on the outside, fastened on with clenched nails. These sides or frames rest, when in their places, on cross-pieces or putlocks, which pass entirely through the thickness of the wall; near the ends are mortises, into which upright pieces are placed, wedged firmly at the bottom up to the sides, already set, to the distance which is to constitute the thickness of the wall, usually about 20 inches at bottom, and gradually diminished as the height is increased; the diminution or inclination is uniform throughout, and in a house of two stories does not exceed 1 foot. The sides or frames are made 10 feet in length, and 3 feet high; the uprights 5 feet long, comprising the tenons, so that they stand up sufficiently above the sides to allow of being secured by ropes. The wedges are 9 inches in length, 1½ at the base, and 20 inches at top, made to fit the mortises exactly, which should be deep enough to permit the bottom to be 2 inches below that of the wall, that the frame may hold within it a portion of the wall already made. The frames at top are steadied by small sticks, which

press them against the outside uprights, held together by the cords at their upper ends; between each pair of uprights it is found necessary to have a strut or one of these sticks; when placed, the cords above are tightened by twisting them with a small piece of wood

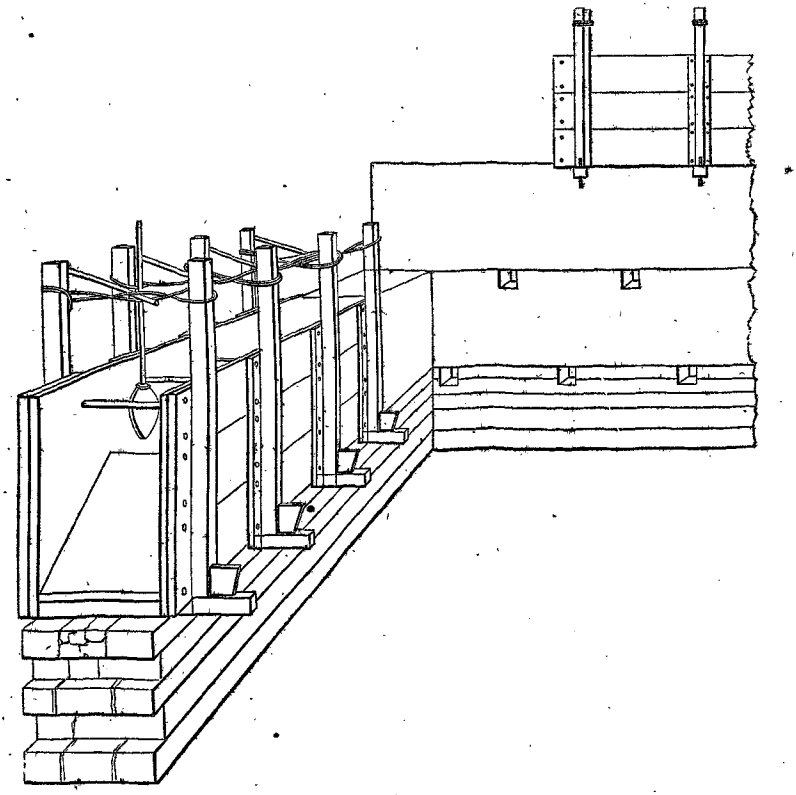


Fig. 605. PISE-WORK.

introduced between them. When the frames are thus fixed, the earth is thrown in, and worked in the same manner as concrete or common mortar; first well wetting the parts about the putlocks, to enable their being easily withdrawn; as many workmen are then employed as there are divisions, one being placed in each compartment.

After the bottom is well-cleaned and lightly sprinkled with water, the labourers bring to the masons the prepared earth in wicker baskets, and tread it with their feet so as to form a bed of an uniform thickness of not more than 3 or 4 inches; they then ram it down, reducing it to little less than half its former thickness; this first bed being compressed, the labourers bring more earth, and form another, spread out and beat in the same manner, and so on till the whole case is filled.

The rammer is a block of wood 10 inches high; at the middle of its height it is square, and 6 inches by 5, diminishing in thickness, and terminated by rounded edges at the bottom: towards the upper part it is terminated by a circular surface 4 inches in diameter, in the centre of which a hole is sunk 1 inch in diameter and 2 inches deep; the circular part at the top being rounded off from the square below, the flat portion of the rammer at bottom must be perfectly smooth and even; a block of ash, elm, or hazel, is usually preferred; the handle is 4 feet 2 inches long, and in ramming it is turned round at each stroke to make the work solid and to unite it with that previously done.

When a wall is commenced, the first frame is put at one of its extremities, and the end is inclosed by two planks united by cleets, secured at the top by two iron cramps; the other part, where there is no end, is terminated by a fall of about 60°. The section of the wall serves to unite the first constructed with that which follows.

After the first stratum is finished, the case or frame is taken down, and placed further along, so that the plank entirely covers the inclined part, which terminates the preceding, uniting it with that about to be made, and the same process is continued. Lintels are placed over all apertures, and when the walls are finished, previously to covering them with plaster, it is necessary to let them remain to dry, according to the climate and time of year. Experience has shown that in an ordinary climate walls of 18 or 20 inches in thickness finished about the commencement of May, are sufficiently dry in September or October for plastering; those finished in July or August may generally be completed before the frost and rain have any effect upon the work: although pisé is formed of earth scarcely wetted, whilst the unburnt bricks of the ancients were *kneaded* with straw and water, it is nevertheless prudent to regard Vitruvius's observation, "not to apply plaster unless the middle is dry." The pisé which is made during the hot months soon dries in the exterior; but the moisture is confined to the centre, from whence it escapes slowly, rising by degrees to the surface; if covered with plaster, it insinuates itself between this and the pisé, occasioning the outer coat to fall off. There is no fear of the action of the air when it is well done, for the drier it is the better the plaster adheres; in the department of Isère there are ancient houses of pisé that have never been plastered on the exterior, and which still resist all the inclemencies of the weather: when the earth is poor, or not consistent enough, by being wetted with lime-water, or grouting formed of mortar, it hardens, the surface becomes improved, and a building might be carried up with its walls so even as not to require any coat of plaster.

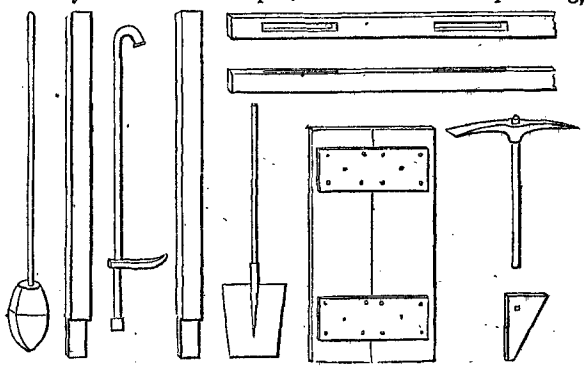


Fig. 606. TOOLS USED FOR PISE-WORK.

The Cob Walls, in Devonshire, formed of clay and chopped straw, are generally 2 feet in thickness, based upon either brick or stone foundations, 3 or 4 feet in height above the level of the soil. Houses so built are warm and healthy, and usually covered with thatch: like pisé-work they require to be carried up at several times, for if hurried the walls will not settle equally, but bulge and incline from the perpendicular. The earth selected is loam mixed with a certain proportion of straw, the whole being well beaten and pounded before it is used. The first height of 4 feet being carried up all round, and the divisions or walls brought to the same level, they are left some weeks to dry and settle, each succeeding rise being diminished in height as it is carried up. The workman stands on the wall to receive the cob, which is pitched up to him, or brought from below, he treading and pressing it down as it is thrown in: after a rise has been made in the wall, the sides are carefully pared down before the next addition is made to it; this is performed by an iron cob parer, which in shape bears some resemblance to a baker's peel. At the openings which are to be afterwards cut out, as the doors and windows, lintels are introduced, due allowance being made for settlement; these rest at their ends on templates or cross-pieces, to which they are secured. When the earth has sufficiently settled and dried, the apertures are cut out, and the sides or reveals carefully dressed; the whole is then coated with a fine stucco or plaster; if kept dry at top and at its foundation, and no water allowed to drip upon it, it will remain sound for centuries: where this construction is adopted for garden walls, it is necessary to thatch the top, or cover it with tiles, to prevent the destructive effects of every shower of rain.

CHAP. VII.

TAR, PITCH, RESIN, &c.

Bitumen or asphaltum is used in the composition of hydraulic cements, and for varnishes and japans: it is a black substance found in the earth; in external character it bears some resemblance to coal; it is a compound of carbon, hydrogen, and oxygen, and generally obtained from the secondary and alluvial formations; its average density is 1·16, and it melts at the temperature of boiling water.

The island of Trinidad contains a tar lake, 3 miles in circumference, and asphaltum is produced in great abundance from springs in many parts of Asia; it is also obtained in considerable quantities near Antibes in France, where it is made into a varnish by dissolving 2 portions of asphaltum with 12 parts of fused amber, 2 parts of resin, 6 parts of linseed oil varnish, and 12 parts of oil of turpentine.

Bitumen has been applied as a covering for roofs and floors, and lining cisterns, and considerable quantities have been imported from the borders of the Lower Rhine: to every pound of bitumen when melted is added 4 or 5 pounds of powdered limestone, chalk or burnt clay; when thoroughly mixed and combined, it is poured out and spread into moulds, previously smeared with a thin coating of loam to prevent adhesion; after the whole has cooled, the mould is taken to pieces, and the bricks or contents are 18 inches in length, a foot broad, and 4 inches thick, weighing about 70 lbs.

Asphaltum may be decomposed by alcohol and caustic potash; its origin is but little known; by some chemists it is supposed to be the product of coals decomposed by volcanic heat or by spontaneous combustion.

Resins.—The Juice of Pine and Fir Trees, like that of the Pistacea terebinthus, has an austere stringent taste; it is viscid and transparent, readily inflammable, and easily becomes concrete. In distillation with water, it yields a highly penetrating essential oil, and the liquor is found to be impregnated with an acid, a brittle resinous matter remaining behind: digestion with rectified spirit of wine completely dissolves all the resinous parts, with which some portion of the insipid gum, or mucilage is also taken up. If this solution be filtered, and diluted largely with water, it becomes turbid, and throws off the greatest part of the oil, the gummy substance being retained: if the solution be subjected to distillation, the spirit carries with it some of the lighter oil, so as to be sensibly impregnated with its terebinthinate odour, and it leaves behind an extract, differing from the resin separated by water, in having an admixture of mucilage. The native juice becomes miscible in water by the mediation of the yolk or white of an egg, or by that of vegetable mucilage, and forms a milky liquor: exposed to the immediate action of fire, the roots and other hard parts of the tree produce a thick, black, empyreumatic fluid, which, containing a proportion of saline and other matter, mixed with the resinous and oily, proves soluble in aqueous liquors, and according to its several modifications constitutes the varieties of tar and pitch. The resinous residue of the several processes to which the matter extracted from pines may be subjected constitutes the varieties of resin, colophony, &c. &c. There are also other products, both natural and artificial, much employed in medicine and the arts.

Tar and Pitch are extensively used for the purpose of retarding the decomposition of wood, cordage, and other articles.

Tar mixed with grease or clay is used for greasing wheels, &c.

Yellow Resin in the proportion of 3 cwt. to 10 cwt. of tallow, for common yellow soap.

Shoemakers' Wax is a composition of pitch, oil, and suet, but it is also made of resin, beeswax and tallow.

Turpentine in all its different forms, is extensively employed in painting.

Tar and Pitch, with a mixture of tow or beaten cables, used for *paying* over the seams of the sides and decks of ships after they are caulked, to preserve the oakum from any wet. Oakum is formed of untwisted old ropes steeped in tar, and in ship-building is indispensible.

Lampblack is used by painters, modellers, and other artists.

Turpentine made from the Scotch fir is so inferior to that obtained from the silver fir that the latter is generally preferred.

Tar is procured from the Scotch pine in great quantities in the north of Europe, and is considered superior to that produced in the United States from P. resinosa, Strobus Australis, &c. The process by which tar is obtained is very simple; it is chiefly from the roots of the Scotch pine. A conical cavity is made in the ground, generally on the side of a bank; and the roots, together with logs and billets of wood, neatly trussed in a stack of

the same conical shape, are let into this cavity; the whole is then covered with turf to prevent the volatile parts from being dissipated, which by means of a heavy wooden mallet, and a wooden stamper worked by two men, is beaten down and rendered as firm as possible above the wood; the stack of billets is then kindled, and a slow combustion of the pine takes place as in making charcoal: during this combustion the tar exudes, and a cast-iron pan being fixed at the bottom of the funnel, with a spout which projects through the side of the bank, barrels are placed beneath the spout to collect the fluid as it comes away; as fast as these barrels are filled they are bunged, and are then ready for immediate exportation. The turpentine melted by fire mixes with the sap and juices of the pine, while the wood itself becoming charred is converted into charcoal.

Pitch is made by putting the tar without any addition into large copper vessels fixed in masonry to prevent any danger from it taking fire, and is there suffered to boil for some time, after which it is let out, and when cold hardens and becomes pitch. Tar and charcoal are obtained in Russia, much in the same manner as in Sweden, from the bottoms of the trunks and roots of trees: in Germany the process is conducted with very great accuracy.

Resin.—The resinous matter which exudes from the pinaster is called by several names in France, even in its raw state: that which encrusts on the sides of the wound is called barras; it is nearly as white as wax, and is used for mixing with that substance for making tapers, to which it gives suppleness and elasticity: the barras is collected only once in the year at the end of the season, and is scraped off with an iron rake: the principal substance which flows from the tree is called galipot, or *résine molle*; this having been collected in the hollow cut of the tree, or in the trough attached to it, is put into large pits or reservoirs capable of containing 150 or 200 barrels each, which pits are dug in the earth, and lined with planks made of the pine trees, fitted so close together as to prevent the liquid oozing through: it is afterwards melted in large copper caldrons set in brickwork to free it from the impurities mixed with it, with a proper chimney to convey away the smoke, as should it be suffered to come in contact with the resin, the whole would probably take fire; it is also necessary to keep continually stirring the caldron to prevent the resin from burning to the bottom.

When the matter is to be made into brown resin, some of the barras is to be mixed with it, and when it is thought to be sufficiently boiled a little is poured upon a piece of wood; when it becomes cold, if it will crumble between the fingers, the resin is ready. It is then poured through a filter made of straw laid horizontally, 4 or 5 inches thick, and run into barrels, where it is left to harden: in this state it is brown and brittle, and called by the French *crai sec*, which is the brown resin of the shops.

Yellow Resin.—When the resinous matter is boiling a quantity of cold water is added, a few drops at a time; this makes the resin swell, and a trough having been previously fixed to one side of the caldron, the matter flows through it to a vessel placed to receive it; from this the operator raises it by a ladleful at a time and puts it back into the caldron, repeating the operation several times, till the resin has become yellow and as clear as wax; it is then filtered through straw into moulds hollowed in the sand, where it is formed into cakes, as sold in the shops. To make these moulds, a circle is first traced in the sand with a forked stick which acts like a pair of compasses; the sand is then hollowed out with a knife, and the bottom and sides of the mould are well beaten with wooden mallets to make them perfectly hard and smooth; the cakes of resin generally weigh from 150 to 200 lbs. each.

Lamp-black is made from the waste materials used in preparing the resin, which are carefully preserved; the straw and pieces of wood are all burnt in a close furnace, or, when the wood of the pine tree is burned for tar, lamp-black is formed on the cover of the furnace.

Pinus Australis, (the long-leaved pine): four-fifths of the houses in Carolina, Georgia, and the Floridas, are built with it; no other species is exported from the southern states to the West Indies, and it is preferred before all other pines in naval architecture: it is sent in large quantities to Liverpool, where it is called the Georgia pitch-pine, and is sold 25 to 30 per cent. higher than any other pine imported from the United States, where it supplies nearly all the resinous matter used for ship-building. The resinous products are turpentine, scrapings, spirit of turpentine, resin, tar, and pitch.

Turpentine is the raw sap of the tree obtained by making incisions in the trunk; it begins to distil in the month of March when the circulation commences, and it flows with increasing abundance as the weather becomes warmer, so that July and August are the most productive months. The sap is collected in boxes, or notches cut in the tree, 3 or 4 inches from the ground, of a size to hold about 3 pints of sap, but proportioned to the dimension of the tree, the rule being that the cavity shall not exceed ¼ of its diameter: these cavities are made in January or February, commencing with the south side, which is thought the best, and going round the tree. The next operation is clearing the ground from the leaves and herbage: about the middle of March, a notch is made in the

tree with two oblique gutters to conduct the sap which flows from the wood into the box or cavity below; in about a fortnight the box becomes full, and a wooden shovel transports it into a pail, and it is then put into a cask: the edges of the wound are chipped every week, and the boxes after the first generally fill in about three weeks. The sap thus procured is used as turpentine without any preparation, and is called pure dripping.

The Scrapings are the crusts of resin that are formed on the sides of the wounds; these are often mixed with the turpentine, which in this state is used in the manufacture of yellow soap, and is called Boston turpentine; in five or six years the tree is abandoned, and the bark never becomes sufficiently healed to allow of the same place being wounded twice.

Spirits of Turpentine are principally made in North Carolina, and obtained by distilling the turpentine in large copper retorts: six barrels of turpentine afford 122 quarts of the spirit; the residium after the distillation is resin, which is sold at $\frac{1}{3}$ the price of the turpentine.

As soon as vegetation ceases in any part of a pine tree its consistence changes, the sap wood decays, and the heart becomes surcharged with resinous juice to such a degree as to double its weight in one year; this accumulation increases.

Tar of the southern states of America is made from the dead wood of Pinus australis, obtained from trees prostrated by time, by fires annually kindled in the forests, or from the tops of those that are felled for timber, &c.: dead wood is productive of tar for several years after it has fallen from the tree. To procure the tar a kiln is formed in a part of the forest abounding in dead wood, which is collected, stripped of the sap wood, and cut into billets of 2 or 3 feet long, and about 3 inches thick, a tedious and difficult task, rendered so by the numerous knots with which the wood abounds. The next step is to prepare a place for piling the billets, and for this purpose a circular mound is raised, slightly declining from the circumference in the centre, and surrounded by a shallow ditch; the diameter of the pile is proportioned to the quantity of wood which it is to receive; to contain 100 barrels of tar it should be 18 or 20 feet wide: in the middle is a hole with a conduit leading to the ditch, in which is formed a receptacle for the tar as it flows out. Upon the surface of the mound, after it has been beaten hard and coated with clay, the wood is laid round, in a circle like rays. The pile when finished may be compared to a cone truncated at $\frac{2}{3}$ of its height and reversed, being 20 feet in diameter below, 25 or 30 feet above, and 10 or 12 feet high; it is then strewed over with pine leaves covered with earth, and held together at the sides with a slight cincture of wood; this covering is necessary in order that the fire kindled at the top may penetrate downwards towards the bottom with a slow and gradual combustion, for if the whole mass were rapidly inflamed the operation would fail, and the tar would be consumed instead of distilled; in fine, the same process is observed as in Europe for making charcoal; a kiln which is to afford 100 or 130 barrels of tar is eight or nine days in burning.

Strasburgh Turpentine, to be good, ought to be clear, free from impurities, transparent, and of the consistence of syrup, with a strong resinous smell, and rather a bitter taste: it is the only turpentine produced by any kind of pine or fir tree, which is used in the preparation of clear varnishes, and its oil sells at a higher price than any other. The proportions for making the oil are 5 lbs. of liquid resinous juice to 4 pints of water distilled in a copper alembic; this is the essential oil of turpentine; and if 1 pint of it be redistilled with 4 pints of water it is called rectified or æthereal oil of turpentine.

Lamp-black.—The apparatus employed for this purpose consists of a furnace, a chimney, and a small chamber or box for collecting the soot: the furnace is about 2 feet 6 inches wide, 3 or 4 feet long, and 2 feet 6 inches high, and it is usually set in brick: on each of the long sides this furnace has an opening near the bottom, which can be shut up at pleasure, by means of a little door attached to it. The furnace has a brick chimney made almost horizontal, to conduct the smoke into the chamber or box: the chimney is from 14 to 16 inches long, and 12 inches broad and high; at the place where the pipe of the chimney terminates is constructed a chamber or box, into which the pipe should enter some inches, so as to carry the smoke into its centre. This chamber is generally about 12 feet square, and 9 feet high in the roof; there is a door on one side, and in the upper part or ceiling an opening 5 or 6 feet square. The walls of the chamber are lined with thin planks of wood or plastered very smooth, and the door is fitted closely into a groove: over the opening in the roof is placed a flannel bag, supported by rods of wood in the form of a pyramid, composed of four pieces of coarse flannel sewed together.

When the lamp-black is to be made, a little of the straw through which the resin and tar have been strained, and some of the other refuse, are put into the furnace and lighted, fresh straw, impregnated with tar, being strewed over the fire, as fast as the other is consumed.

The smoke passes into the chamber, and deposits its soot on the walls, and on the flannel bag, from both of which it is detached, after the whole of the straw and refuse have been burned, by striking the outsides smartly with a stick. The flannel pyramid acts as a filter to the lighter part of the smoke, retaining the soot, and permitting the heated air to escape

into the atmosphere. The door of the chamber is then opened, and the lamp-black, being swept up, is packed in small barrels made of the wood of the spruce fir for sale.

In the Landes the furnace and the chimney are in the open air, and the chamber only covered with a tile roof; but in Germany the whole apparatus is constructed in a barn-like building, about 24 feet long, 12 feet wide, and 10 feet high.

Glass.—This transparent, impermeable, and brittle substance, consists of many varieties, which are differently composed, and applicable to as many purposes: the manufacture of glass is of the highest importance, and now that all restrictions are withdrawn to its improvement, we may expect to find it rendered not only cheaper but better. It was known not only to the Egyptians, but also to the Phœnicians, whom Pliny says were the inventors of the manufacture; both Sidon and Alexandria were famous for the production of beautiful glass, which was cut, engraved, and tinted with a variety of colours, some specimens of which equalled the precious stones in brilliancy of effect. Rome was also celebrated for its manufacture, and Nero is reported to have given as much as 6000 sesterces for two glass cups: before Colbert introduced an establishment into France for blown mirror-glass, Europe generally was indebted to Venice for all that appeared in commerce: it was not made in London until 1557. Glass is made by fusing silica with a due proportion of alkali, which serves as a flux to the silica, and makes the whole transparent: it may be said to consist of one or more salts, which are silicates, with bases of potash, soda, lime, oxide of iron, alumina, or oxide of lead.

The silica ordinarily made use of is sea-sand, which consists chiefly of quartz, and the finest quality is obtained on the coast of Norfolk, near Lynn: the common black flint is also used; after it has been heated red-hot, and plunged into cold water, it breaks to pieces, and becomes so brittle that it is easily ground into a fine powder. The alkali is either potash or soda in a state of carbonate: borax is the flux for the finer sorts of glass, but for the more common kind lime is substituted: two oxides of lead are used, viz. litharge and minium, which give to the glass greater powers of refracting light, and that of suddenly changing its temperature without cracking. The white oxide of arsenic is also a flux, and in any large quantity will give the glass a milky hue, which increases with time.

Soluble Glass is a simple silicate of potash or soda, or of both these alkalies; crown glass is a silicate of potash and lime; common window-glass is a silicate of soda and lime, or red potash; bottle glass is composed of silicate of soda, lime, alumina, and iron.

The common crown glass for ordinary windows is compounded after the following proportions; 450 pounds of kelp, dried and ground, 325 pounds of Lynn sand, and 25 pounds of slacked and sifted lime. The kelp, which is the alkali, differs so much in quality that its proportions continually vary: arsenic is added to facilitate the fusion, and oxide of cobalt with ground flint introduced to improve the colour. By measure, five parts of fine sand and eleven parts of ground kelp or soda is another proportion for common crown glass.

Flint Glass is composed of silex, to which is added carbonate of potash and red lead or litharge, the latter giving the glass its great specific gravity, its superior transparency, its ductility and powers of refraction. The materials after preparation are put into a crucible of Stourbridge clay, which holds about 1600 lbs. weight of fused glass; a double stopper covers the mouth of the crucible, and as it is not luted, the carbonic acid gas, or excess of oxygen, has the means of escaping: a strong, rapid, and intense heat for sixty hours is required to drive off the gases and to fuse the metal, during which process the surface is regularly skimmed of all the impurities that arise.

Flint plate glass, for optical purposes, is thus prepared; seven pounds of the metal is taken out of the pot when at a certain point of fusion, in a conical-shaped ladle, and then blown into a hollow cylinder, which is cut open and flattened into a sheet 20 inches by 14, and varying in thickness from $\frac{3}{8}$ to $\frac{1}{4}$ of an inch; the plate is then annealed, and afterwards cut and ground into the required form.

When glass is not sufficiently annealed, it is put into tepid water, which is heated and maintained for some hours at a boiling point, and is then suffered to become gradually cold; unannealed flint glass, heated and suddenly cooled in water, resembles in its appearance a mass of crystals, from whence it has been supposed that the process of annealing renders the glass incapable of polarisation, in consequence of its becoming more compact. A barometer tube 40 inches in length, unannealed, heated, and suddenly cooled, would contract $\frac{1}{16}$ of an inch, and if done by the usual manner, its contraction would be double, or $\frac{1}{8}$. The red tint given to glass by manganese is destroyed by annealing, and the best fuel for melting glass in the furnace is oven-burnt coke mixed with screened coal: in plate glass there is no lead; in consequence it is purer, and more homogeneous than common flint glass.

Plate Glass.—Common salt or the muriate of soda is decomposed by the subcarbonate of potash, when both salts are in a state of solution and subjected to heat; an alkali so obtained is dried by being continually boiled: 1 pound of pure soda, and 4 pounds of sand, produce a hard glass, which neither water nor the mineral acids will affect. The best plates are formed out of 720 pounds of Lynn sand, 450 of alkaline salt, 80 of slacked quick-

lime, 25 of nitre, and 425 pounds of broken plate glass; this generally, if well managed, produces 1200 pounds weight of plate glass.

On the continent the best mirrors are formed with 300 pounds of white quartz sand, 100 pounds of dry carbonate of soda, 43 pounds of lime slacked in the air, and 300 pounds weight of old glass; $\frac{1}{2}$ per cent. of the weight of soda is added in manganese. The atomic constitution of glass consists of five atoms of silicic acid, one of oxide of lead, and one of potash.

After the materials are thoroughly prepared and refined, they are put into a cistern, the temperature of which is previously raised to that of the glass, and when the cistern is full, it remains for a considerable time in the furnace, until all the air-bubbles are dispersed; after this operation it is ready for casting. The table for this purpose is formed of a cast-iron plate, supported on pillars of considerable strength; the metal is then suffered to flow readily and equally from the furnace into a cistern, which is carried to the table, it being first heated with hot ashes and carefully cleaned. The surface of the metal has the scum taken off by a copper instrument, and the cistern that holds it is then hoisted and swung by means of a crane over the end of the casting-table, where it is overset, and the metal immediately flows equally over it. A copper roller is passed over the fluid, and the surface is thus rendered comparatively smooth; by means of this roller the necessary thickness is given to the plate, as it runs upon a fillet placed on the edges of the table: after plates are cast, they are taken to the annealing chamber, where they remain for twelve or fifteen days, placed in a horizontal position.

CHAP. VIII.

GEOMETRY.

GEOMETRY, derived from the Greek words which signify land and the method of measuring it, is employed in estimating the length of a line, the area or superficial contents of a figure, and the cubical or solid contents of a body, and is usually divided into theoretical and practical. Egypt gave birth to the study; from thence it was imported into Greece, and among the refined and intelligent inhabitants of that classic land it arrived to a degree of perfection that succeeding ages have but little improved.

Theoretical geometry is founded on ideas, or those perceptions of the mind which resolve and demonstrate the truth of any proposition; it is the method of defining exactly the notions we form of any particular figure.

Practical geometry, so important to the civil engineer, is that division which enables him, by the aid of various mathematical instruments, to carry into operation the principles taught by theory, and to trace and define the boundaries of any figure that may be required to be set out for mechanical or other purposes. This branch is subdivided into *Trigonometry*, *Planeometry*, and *Stereometry*.

Trigonometry is the art of measuring heights and distances by means of triangles; for example, it enables us to ascertain the distance between the two spires A and B, which are separated by a wide and deep river, and consequently inaccessible. It shows us an easy method of laying down the map of a country, and defining upon it the inequalities of the surface, as the depths of valleys or the heights of mountains; it enables the mariner to map an inaccessible coast, to form a chart which shall guide him through deep and safe channels, and to shun the rocks and shoals which would destroy his vessel.

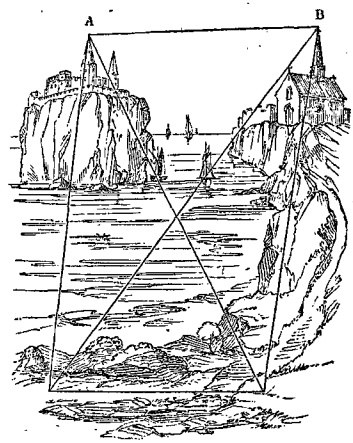


Fig. 607.

Planeometry is applied to ascertaining the area or superficial contents of any surface; it shows the land surveyor the method of finding the number of acres contained in a given district of country, or of subdividing it into any number of equal or unequal parts.

Stereometry or mensuration is the art by which we ascertain the contents of a cube, or any solid figure; that is to say, the quantity of cube feet or yards it may contain.

The elements of practical geometry, or leading definitions, may be thus described: — a point is the extremity of a line without dimensions, or even length, breadth, or thickness; hence, by some it is merely held as an idea; but Euclid, the earliest and ablest teacher of the science, considered it the beginning or nucleus of all quantity. It is therefore the smallest portion of matter, or of an object, that the eye can distinguish, or which may be defined or expressed by a pencil, or instrument of any kind.

A point may be established at any given place, and may be marked by a stake or staff, or by the end of a pair of compasses.

The point of junction is that where two lines meet, as at Q. The point of intersection is where two or more lines cross each other, as at A.

The point of incidence, A, is that from whence the line P A is reflected back from the line A C or B C. A point has neither length, breadth, nor thickness; a line has length only; a surface has length and breadth, and a solid has, in addition, thickness: one dimension is required then for a line, two for an area, and three for a solid body. The edges which bound a solid are lines, and where they unite may be considered points; these may all be imaginary, but they are necessary to establish, before we can arrive at the true

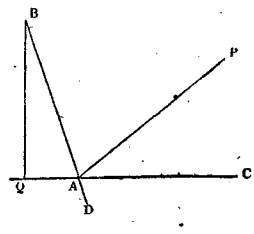


Fig. 608.

estimate of quantity, or the contents of either surfaces or solids.

Tangent point is that at F, where the straight line V X touches the curve of the circle N, at a part of its circumference G O F, or at G, where two circles touch each other, without cutting; N is the central point of the circle: right lines drawn from this point to the circumference are its radii; the two points which bound each being the centre, and a dot on the circumference. The diameter passes through the centre, comprises twice the radius, and may be defined as bounded by two points, situated somewhere on the outline of the circle. This circumference may be also supposed to be divided by points into a number of degrees, and the divisions between by others, *ad infinitum*, until the entire figure is composed of points, or forming a polygon with an infinite number of sides.

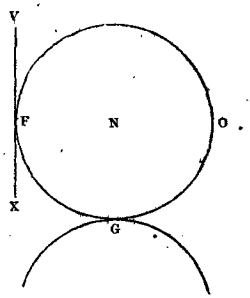


Fig. 609.

Station point is the place from whence an observation is made, and the spot immediately beneath the centre of the instrument used; R is such a point.

Distance point is a stone or hole in an object, remarked in taking an observation; V in the tower serves for such a point of sight, and is used to denote the horizontal or level line by which the height of the tower T may be ascertained.

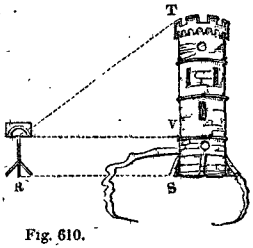


Fig. 610.

Inaccessible point is one that cannot be approached, as S, the water which surrounds the tower not permitting an easy access to it.

Lines have length only, and are the boundaries of all figures; they may be considered to pass from one body to another, without being visible; C D is an imaginary line from the point of the pyramid to the stone.

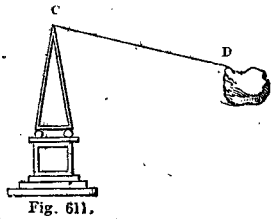


Fig. 611.

A right line, as that of G H, is straight, and lies evenly between two points, neither ascending nor descending, but is the shortest distance between the objects.

A curved line has no portion of a right line, but is concave on one side and convex on the other.

G H is a *perpendicular line* standing on K L, the angles formed on each side being equal; G H L and G H K both being right angles. The plummet makes, when it is dropped, a perpendicular line, as at N.

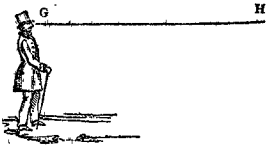


Fig. 612.

The column L is a perpendicular line standing on its base M, or rather it diverges or tends to the centre of the earth, the line with which it is perpendicular being a tangent to the earth's circumference: falling bodies tend towards a point at its centre, and our ideas of a perpendicular line must always be with reference to a limited base, or it must be considered a diverging line; for the sides of buildings continued to a great height, and maintained perpendicularly, would, according to our usual notions, require that the area of the upper floor or top should be larger than the one below: the walls or lines that bound them, to be upright, must be radii, and consequently diverge from each other as they are continued upwards; in practice it is not necessary to have any other guide than the plummet, which dropped from a height falls to the centre, and any material disposed within such a line gravitates to the same point. Spires of churches are rarely found to have the point at their apex directly over the centre of the area of their base; that at Salisbury is nearly 2 feet inclined beyond it; it is extremely difficult to ascertain one point by the plummet that is directly over another, when the height is considerable. Columns are rarely found placed truly perpendicular; their internal faces, as those towards the cell of a temple, are sometimes less inclined or diminished

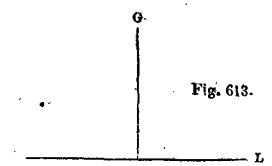


Fig. 613.

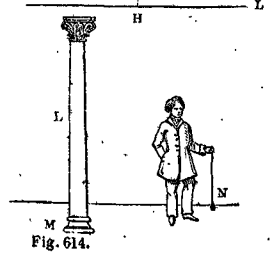


Fig. 614.

than those on the outside; hence some have supposed that such an arrangement was intended to produce a better effect.

The line O P, in the triangle O Q R, is a perpendicular, because it falls at right angles with the base; O P Q and O P R being both right angles. In practice, a perpendicular or right angle is set out by the numbers 3, 4, and 5; for example, if Q P is made 3 feet, P O 4 feet, and Q O 5 feet, O P will be perpendicular; or if O P is made 3000 feet, P R 4000, and R O 5000, the result will be the same.

S T is perpendicular to the side T, because it is at right angles with it; hence the radius of a polygon, when it falls on the middle of one of its sides, is also its perpendicular.

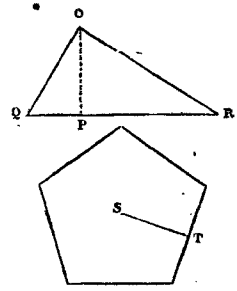


Fig. 615.

An inclined line, as V X, is that which is neither parallel nor perpendicular with another, as that of Y Z.

Parallel lines are those like A B, C D, and E F, which may be drawn to any length, and yet never approach. All lines which preserve an equal distance from each other are called parallel lines.

The two curved lines S T, V X are parallel, although they are not of an equal length.

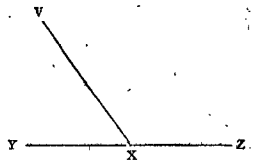


Fig. 616.

This subject has ever been considered difficult of explanation, and much has been written upon it. Some writers have exerted themselves to demonstrate that two parallel lines, when they meet a third, are equally inclined to it, or make the alternate angles with it equal. Euclid has shown that if a straight line meet two straight lines, so as to make the interior angles on the same side of it less than two right angles, these straight lines, being continually produced, will at length meet on the side on which the angles are which are less than two right angles; but this is not so evident, and many celebrated geometricians have attempted to make our author more clear upon this point. Some have asserted "that straight lines are parallel which preserve always the same distance from each other;" but the correct definition would be, that "two straight lines are parallel when there are two points in the one from which the perpendicular drawn to the other, and on the same side of it, are equal." The difficulty in such a statement consists in showing that all the perpendiculars drawn from the one of these lines to the other are equal.

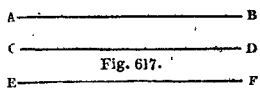


Fig. 617.

Fig. 618.

Parallel lines by some are said to be those which make equal angles with a third line towards the same parts, or make the exterior angle equal to the interior and opposite; this definition requires only that it should be proved that all the straight lines which are equally inclined to one *given* straight line are equally inclined to *all* the other straight lines which fall upon them.

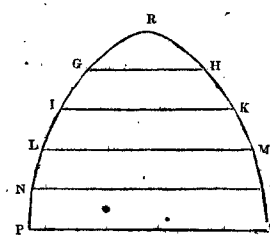


Fig. 619.

Ordinates are lines in a parabola, R P Q, which are drawn parallel with the base, as G H, I K, L M, N O, and are derived from the Latin *ordine*. A straight line drawn from any point in a curve perpendicularly to another straight line, which is called the abscis, is an ordinate. The abscis and ordinate together are called the *co-ordinates* of the point. The situation of a point in a plane is determined, when its distances from two straight lines in the same plane are known; and when a series of points are so situated in respect of each other that the co-ordinates of each have the same mathematical relation, they form a curve, the nature of which is expressed by the relation of the co-ordinates.

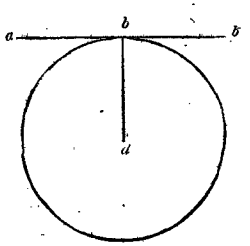


Fig. 620.

Horizontal line, or apparent line of level, is that which cuts or touches at right angles a line supposed to pass through the centre of the earth; the line *a b*, resting on the perpendicular *c d*, is horizontal, and all lines parallel with this are deemed horizontal.

Level line is that traced out by the instrument made use of by bricklayers and other artisans; the face *g l* is level when the plummet hanging at *e* falls perpendicular over a line traced to *f*, which is set out at right angles with it; the line of true level is, however, a curved line, which is at all points equally distant from the centre of the earth; for example, in a length of 5000 feet, an allowance must be made of nearly six-tenths of a foot, to reduce the line levelled to its true level.

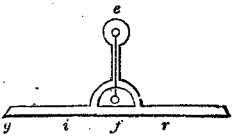


Fig. 621.

The plane of the sensible horizon is indicated in two manners, first by the direction of the plummet or plumb line, to which it is perpendicular, and by the surface of a fluid at rest: levels are therefore formed either by means of the plummet line, or by the use of a fluid applied in an instrument made to contain it.

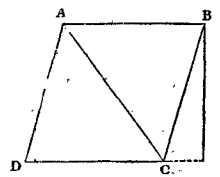


Fig. 622.

The Gunner's Level is a triangle with a scale, on which the plumb line falls; by which arrangement the inclination of a straight line to the horizon can be measured. The plummet hangs from the point where the two equal legs of the level join at right angles, and this plays over a quadrant that is divided into twice forty-five degrees from the middle; so that when the plane on which the ends or legs of the level rest is horizontal, the thread of the plummet falls over zero; when it falls over any other point, the degree marked on the scale indicates the inclination of the line to the horizon.

Diagonal line, as that in the figure A B C D, which is drawn from A to C, cutting it into two parts, and dividing the rhombus into equal portions.

Master Line is a term given to that which is set out or boned through a country or field to be mapped, (this latter technical expression being possibly derived from the French word *borner*, to limit or confine within bounds,) and from which spring a number of triangles or other figures. I F is a base or master line, being the longest which can be traced in the plot E F G H I.

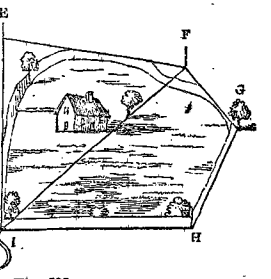


Fig. 623.

The use of a map is to exhibit the boundaries of a country, and the relative position of the several parts, in reference to their just and proper proportions; this may be done very accurately on a globe, but without the same spherical surface; it is not possible to represent any considerable area in such a manner that the distance of places shall retain the same proportions which they have on the globe; for small maps, or the plans of an estate, lines may be boned through for the construction of angles or other figures without difficulty.

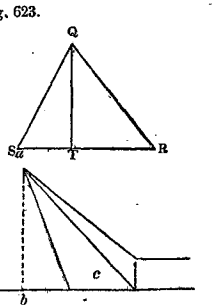


Fig. 624.

Heights.—It is highly important that we should have the means of determining accurately the relative altitudes of points on the earth's surface: when it is required to ascertain the height of one point or station relatively to another, and also the relative heights of a number of points above a common horizontal plane, as for tracing the line of a railway, levelling is practised.

The height of a figure is a perpendicular let fall from its highest point, as Q T in the triangle Q R S, or the line *a b* in the inclined pyramid *c*.

Line of heights is that which descends from the top to the bottom of a building; O P, for instance, is such a line, from whence the observer, placed with the instrument Y M, is enabled to mark out at N, or any other point, a determined distance or measurement.

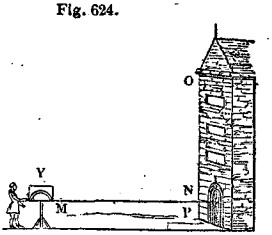


Fig. 625.

Scales are right lines of any length, divided into equal parts; the scale A B, for instance, is set out or divided into 50 feet, and one portion attached subdivided into feet; the other is marked with 500, each portion containing 100, and this again subdivided into tens.

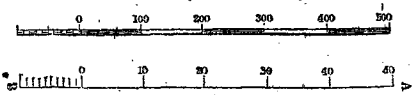


Fig. 626.

Plans always have a scale attached to them; in that of the fort F its length and divisions are made with reference to one of its sides, as H or I, which may be supposed either 50 or 500 feet in extent. In the figures M, N, the scales K and L may be made to agree with the length of either of its sides, and by reducing or enlarging the scale, the figures to be traced may be made larger or smaller, care being taken to set out the angles correctly.

Working drawings are usually upon a large scale, as they are intended for the artizans to set out their respective labours; they should be of a size to express accurately the parts of the machine or other object to be executed: an outline is generally sufficient for the purpose; sometimes a quarter scale is required, where the parts are intricate or small, at other times a 12th or 24th part of the real size: for fortifications or earth works the plans are made upon a scale of so many chains or feet to an inch, and when laid down accurately, they may be diminished or increased by adopting different scales. A very easy and simple method of performing this is by covering the designs with squares or lines parallel and at right angles with each other; when the plan is irregular, as that shown at M and N, it is necessary to bound them by a square, or, taking the longest sides for a base line, to construct one upon it, and then set out accurately all the angles, or, according to the degrees they measure, a diagonal line may be drawn from the points of the two extreme angles, and then parallelograms and squares may be constructed on each side of it to embrace the other portions of the plan, and afterwards the figure which bounds the whole may be reduced or enlarged; the subordinate parts will all have the same relative value to each other, and one will be a fac-simile of the other, though on a different scale.

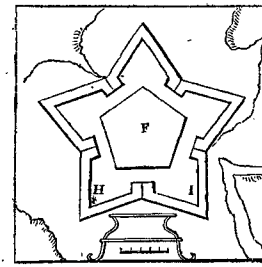
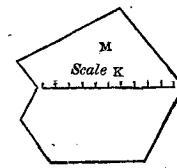


Fig. 627.



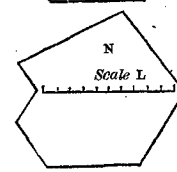


Fig. 628.

Wavy or curved Lines rise and fall, as indicated at A C E D F B, and when a circle is struck from the centre V, the line N is a curve.

We may suppose the surface of the earth to present a wavy or curved form, which it is required to ascertain; this is performed, as we shall hereafter see, by means of an instrument called the level; the wavy line is measured from another, which is set out by means of upright staves and rods with great accuracy, and where the inequalities are numerous, it is requisite to make the measurements frequently; when the eye of an observer is placed on a level with the plane which presents an undulatory surface, it is difficult to measure the rise and fall without establishing a number of fixed points, or placing in each hollow a perpendicular staff that can be seen from the station point; if these rods were all so cut that the eye could see their tops in one continued line, the level might be established, or the inequalities measured sufficiently for ordinary purposes, but where great nicety is required, instruments carefully adjusted are necessary, as the eye is easily deceived in long distances.

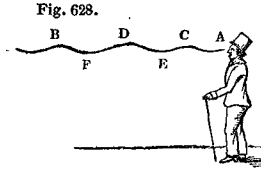


Fig. 629.

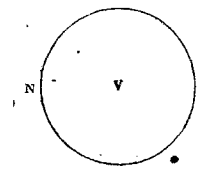


Fig. 630.

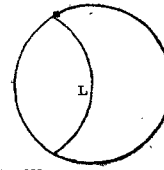


Fig. 631.

Spherical Lines are those which may be traced on the globe L.

Spiral Lines proceed with a regular and gradual enlargement of distance round the volute P to the termination at O. This name is given to all those curves which have the peculiar property of receding from the centre while they continue to revolve about it; there are many varieties, as the equable, the hyperbolic, the logarithmic, spiral, and others: the first was ably treated upon by Archimedes, who also showed the rules by which it could be generated.

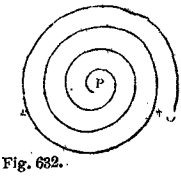


Fig. 632.

Of Angles.—Two right lines drawn from the same point, and diverging from each other, form an angle; the two lines A B and C B form the angle A B C, because these two lines touch each other, or cross at the point B. An angle is commonly designated by three letters, and it is usual to place in the middle letters which mark the point of divergence, which in this case is B.

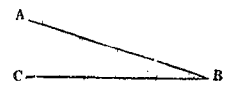


Fig. 633.

At the point D several angles unite, as the angle E D F, F D G, G D H, H D I.

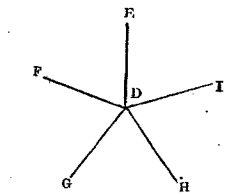


Fig. 634.

The magnitude of an angle does not depend on the lines which bound it, but upon their divergence from each other; the lines which proceed from the point D, though continued to an indefinite length, do not in any degree alter the angle; it is only greater than another when lines of equal length are placed at a greater distance apart.

Opposite Angles are those formed by the intersecting of two right lines; the angle R P O is opposite the angle S P Q, and for the same reason the latter is opposite the former.

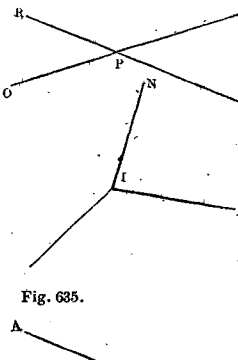


Fig. 635.

The angle L I M is not opposite to that of M I N, because it is not formed by the same prolonged lines.

Euclid defines a plane angle to be the inclination of two lines to one another which meet together, but are not in the same direction: Apollonius, however, gives a somewhat more obscure definition; he calls it the collection of space about a point. Euclid's idea in strictness can only apply to acute angles, and from it we can form but very inadequate notions of angular magnitude.

The angular point B, it must be remembered, is always considered to be the point of the angle A B C.

The solid angle is formed by the meeting of two plane angles, which are not in the same plane, in one point; such magnitudes admit of no accurate comparison one with another; no multiple or submultiple of such angles can be taken, and we have no method of expounding the ratio which one bears to another; on this account our reasoning is limited to the plane angles which contain them.

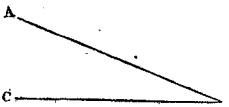


Fig. 636.

The visual angle is formed by two rays of light, or two straight lines drawn from the extreme points of an object to the centre of the eye, which we may suppose at B.

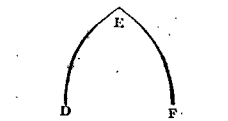


Fig. 637.

A Curvilinear Angle is formed by two curves, as the cog of a wheel; the lines D E F form such an angle struck from the centres F and D.

A mixed Angle has a curved side united with a straight line, as G H I.

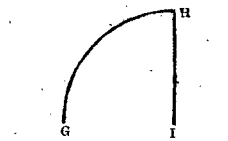


Fig. 638.

The Central Angle of a figure is that which is formed on the centre of a figure by the intersection of two lines; the angle L K M is a central angle, because it is formed from the centre of the pentagon P O M L N, by the meeting of the two right lines L K and M K.

The Angles of a Polygon are those formed by the sides of the figure, as N L M.

The Angle of a demi-polygon is that which is made by the line drawn from the centre and the side, as K M L.

The Angle of a Circumference is that of which the summit bases on the circumference, as L M N.

The opposite Angle to a side is that which is over against the side which serves for a base, as L K M.

A Salient Angle is that whose point is towards the outside of the figure, as O P N.

A re-entering Angle is that whose point is towards the inside of the figure, as O Q M.

Adjacent Angles are those formed at the extremities of the same side, as K M L and K L M.

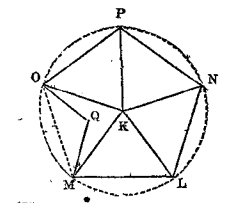


Fig. 639.

An Inaccessible Angle is formed by two lines which meet in a point, as A B C, the point of the pyramid B being supposed inaccessible, or which cannot be reached so as to measure it.

A solid Angle is the point where more than two planes or superficies of a solid touch each other. The point E is a solid angle between the three faces H, I, K: all points or angles of solid rectilinear bodies, of whatsoever figure, are solid, as more than two faces meet each other.

The cube is bounded by six squares, and constitutes one of the five regular Platonic bodies, which being placed beside each other fill up the space about a point; there are here eight solid angles formed by the junction of the six planes. The duplication of this solid, or the finding of the side of a cube, containing exactly twice as much as another, was for a long time a problem of difficulty, and which cannot be solved by means of the straight line and circle, which were the only lines the ancients made use of in constructing their geometrical solids.

The Opening, or Size of an Angle, is measured by the number of degrees of the circumference of a circle contained between the two sides, the circle always having the summit of the angle for a centre. L M N is of 60 degrees opening, because there are so many contained between the lines L M and N M, or 60 parts out of 360 of the circumference, which is described, taking M as a centre.

In geometry generally, the term *right* is applied to such angles as have one line perpendicular to the other, as where the angle is one of 90 degrees. The Platonic school of mathematicians was frequently employed to discover rational numbers, which should designate the sides of a right-angled triangle: Pythagoras gave the formula $n\frac{n^2-1}{2}$ and $n\frac{n^2+1}{2}$, where n is odd: Plato gave $2n$, n^2-1, and n^2+1 where n is either odd or even. For practical purposes the numbers 3, 4, and 5, effect this: suppose P Q to be 4 feet, P O 3 feet, and the distance from Q to O to be 5 feet, then we know that we have a right angle, for if to the square of 4 we add the square of 3, and then extract the square root, we obtain 5.

The Angle O P Q is for the same reason one of 90 degrees, because the distance between O P and P Q is a quarter of the circumference of the circle which encloses it.

A Right Angle is that made by a right line falling perpendicularly on another, and which contains in its opening a quarter of the circumference; A B C is a right angle, because the line A B falls perpendicularly on that of B C; a right angle is square, and is used as such by all workmen.

The square G, formed with either wood or metal, enables us to set out very accurately a right angle, or any other figure which has its sides perpendicular to the base; for drawing we have one limb fixed into a cross piece that gives it the form of a T: with such a square we can construct, by means of a drawing board nicely adjusted, lines both parallel and perpendicular.

The square used by mechanics is formed like an L, and should be a true right angle; this can always be ascertained by drawing a line along the edge of the blade, and then reversing it; if the line and blade in the new position correspond, the square is pronounced to be true.

A rule or square, formed of wood or ivory, like a right-angled triangle, is used for drawing perpendicular lines; this is laid with one side to the given line, and the perpendicular required is drawn by the edge of that at right angles to the first.

T squares are sometimes made of two equal pieces, kept together by a screw; the blade is fixed into one of these, flush

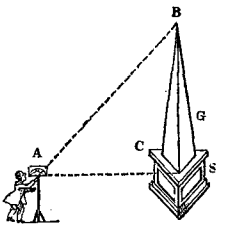


Fig. 640.

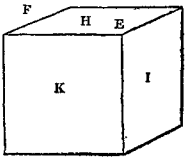


Fig. 641.

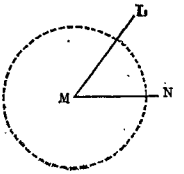


Fig. 642.

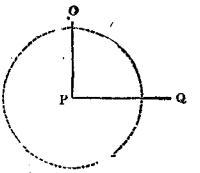


Fig. 643.

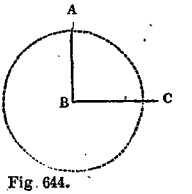


Fig. 644.

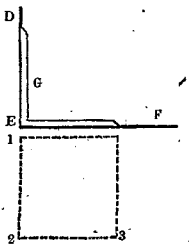


Fig. 645.

with its inner face: if the other be applied to the edge of the drawing board, the former, with the blade, can be turned on the screw as a centre to any angle; the screw being then tightened, parallels forming that angle with the side of the board can be drawn; and, if applied to an adjoining side, the blade will be at a right angle to its first position; these bevel squares are exceedingly useful to architectural draughtsmen and engineers.

An Obtuse Angle is greater than a right angle, and contains more than a quarter of a circle or 90 degrees; the angle H I K exceeds the angle L I K, or that of the quarter of a circle described from I as a centre.

The magnitude of an angle does not depend on the lines by which it is formed, but, as has been observed, upon their distance from each other; the obtuse is therefore greater than the acute, in consequence of the lines which constitute it being farther apart, or diverging more than those of the acute: the legs of a pair of compasses may be made to exhibit this; when separated but little, we have an acute angle, and opened more and more we obtain the obtuse, the rule joint upon which the limbs move being considered the point of the angle.

When a point of the compasses is applied to N, and a circumference described, the arc contained between the lines which diverge from the centre, as M and P, serve to measure the angle.

An Acute Angle is less than a right angle, as M N O, because also it is less than a quarter circle or 90 degrees.

A Right-angled Triangle has two sides at 90 degrees from each other, and the line which unites them is called the hypothenuse, as K L.

An Obtuse-angled Triangle is that which has its angle greater than a right one.

An Acute-angled Triangle is that which has its angle less than a right angle: consequently an equilateral triangle is acute; in general every triangle has two acute angles.

The triangle N O P is obtuse angled; A B C an equilateral triangle; R Q S an isosceles triangle; F E D a right angle; and L M K a scalene triangle.

Rectilinear Figures are those which are contained or bounded by right lines, as T K L M.

In the square the right lines which form the sides fall upon parallel lines, and make the alternate angles equal, and the lines being perpendicular to one of the two which are parallel, it necessarily follows it must be so to the other. In a quadrilateral figure the surface is comprised within four equal right lines, which are called its sides, with all its angles right ones.

Curvilinear Figures are such as are bounded by curved lines, as N O P.

A plane figure contained by one line, called the circumference, is such that all straight lines drawn from the centre to it are equal to one another. The straight line and the circle are the only figures admitted into plane or elementary geometry, all questions in mathematics depending on the intersections of straight lines with straight lines, straight lines with circles, or of circles with circles. All figures are formed by the intersections of planes with solids, and are termed problems, for the understanding of which it is necessary to have them bounded by straight lines and circles. The circle is a very important figure in trigonometry or the measurement of angles, and the ratio that the circumference bears to the diameter is a calculation that long exercised the heads of the learned: in the two concentric circles of the figure, their relative circumferences are in proportion to their diameters, as N O and P.

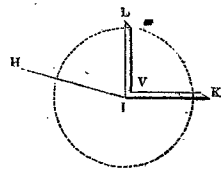


Fig. 646.

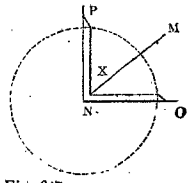


Fig. 647.

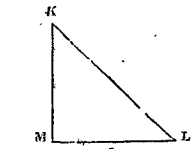


Fig. 648.

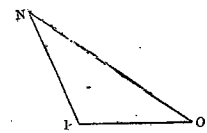


Fig. 649.

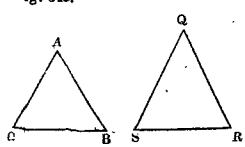


Fig. 650.

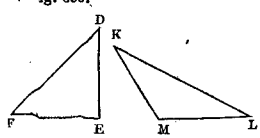


Fig. 651.

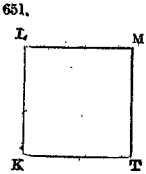


Fig. 652.

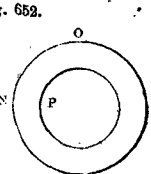


Fig. 653.

Mixed Figures are bounded both by lines and parts of circles, as Q R S.

Regular Figures are all formed of equilateral and equiangular polygons; circles can be described within and about such figures; such can also be explained by geometrical methods in particular instances. General expressions for the radii of the circles explained within and about them, and for their areas and angles can be given: thus if we denote the number of the sides of the polygon T by the expression n, and if u° represent the n^{th} part of 1800, we shall have a being the side $R = \frac{1}{2} a$ cosec. u°, $r = \frac{1}{2} a$ cot. u°, area $= \frac{1}{4} n a^2$ cot u°.

That figure which has its sides all of equal length, and its angles equal, as those of the hexagon T, &c., is regular.

Figure, in geometry, is often used in two different senses: in one it implies a space bounded on all sides, whether by lines or planes; in another it signifies the representation only of the object of a theorem or problem, and enables us to render its demonstration or solution more easily understood.

An Irregular Figure is that whose sides are unequal, and its angles various, as V, the sides X Y, Y Z, Z 5, being all unequal.

Triangles are figures contained within three sides, and form three angles, as A B C.

The following are some of the properties of plane triangles: the greater side is opposite the greater angle, and the difference of any two is less than the third side.

Compasses have been formed with three legs for the construction of maps, by which three points can be taken off at one time; these have two legs that open in the usual manner, and the third made to turn round an extension of the central pin of the other two, besides having a motion of its own on the central joint.

A Rectilineal Triangle is formed by three right lines, as A B C.

A Spherical Triangle, T, is that which has its three sides curved.

Equilateral figures inscribable in circles are necessarily equiangular, but the converse does not always hold true: when the number of sides is odd, the equiangular figure inscribed in a circle is always equilateral; but when the number of sides is even, they may either be all equal, or one half equal to each other, and the other half equal to each other, though not to the former, the two sets being placed alternately: this was well understood by the masons of the middle ages, as we see expressed in the tracery of the windows, and the mosaic patterns they have left us on the pavements and walls of their several buildings. Pisa is rich in such illustrations, and it seems to have been a favourite study to construct equilateral and other angles within the circle when the cathedral in that city was built.

An Equilateral Triangle has its three sides equal, as D E F.

An Isosceles Triangle has two of its sides equal, and of the same length, the third being either greater or less: V and Y are mixed triangles. Among the properties of the isosceles triangle is one in particular, viz. the angles at the base are always equal, and as the demonstration given by Euclid is the first, and somewhat intricate and difficult for learners, it has been termed the *pons asinorum*.

A Scalene Triangle has its three sides unequal, as G H I.

A cone or cylinder is said to be scalene if its axis is inclined towards its base; but the term oblique would be more appropriate.

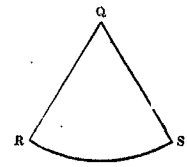


Fig. 654.

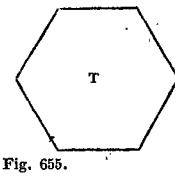


Fig. 655.

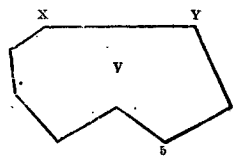


Fig. 656.

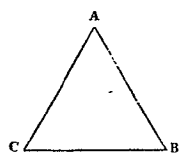


Fig. 657.

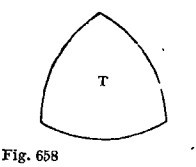


Fig. 658

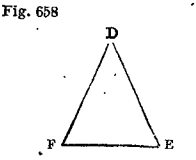


Fig. 659.

Fig. 660.

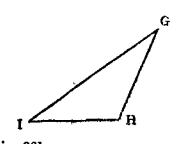


Fig. 661.

The three internal angles of every triangle are equal to two right angles, or to 180 degrees. From the summit of the angles N O P describe circles, each divided into 360 degrees, and if we add the degrees contained between the lines of the three angles, as P N O 68, N O P 60, O P N 52, we shall find the contents of the three angles together 180 degrees, or the double of two right angles.

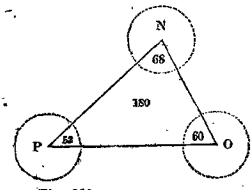


Fig. 662.

A Common Triangle is that which is comprised between two triangles, of which it contains an equal portion, and which has for its base the same as that of the two triangles comprised between the same parallels. The triangle G H I is common with respect to Y H I and Z I H, because it is comprised between two triangles

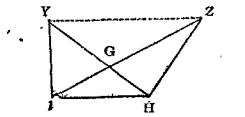


Fig. 663.

Figures of Four Sides, or Quadrilaterals:—

A Square has four equal sides, and four right angles, as A B C D.

In the rectangle A B C D, the side B C is parallel to the side A D, and the side A B parallel to the side D C. The line A B is perpendicular to the two lines B C, A D, the two other lines are therefore parallel: in like manner the line A D is perpendicular to the two lines A B, D C; the two lines A B, D C, are therefore parallel.

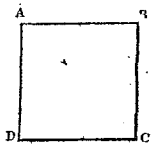


Fig. 664.

A Parallelogram has four right angles, but its sides are unequal, two being shorter than the others, as E F G H.

The opposite sides of rectangles are equal; and a line falling upon parallel lines, as we have seen, make the alternate angles equal.

By *superposition* the relative proportions of the square and parallelogram can be ascertained; this method was very much used by the ancient geometricians: when two figures so applied are found to coincide and to fill up the same space, we infer that they are equal each to each.

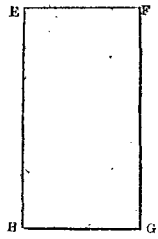


Fig. 665.

When Euclid endeavoured to prove that two triangles which have two sides of the one equal to two sides of the other, and also the angles contained by those sides, equal, he supposes one triangle to be placed over the other: on such a principle we compare rectilineal figures, for if it be shown that the square when placed over the parallelogram occupies only two-thirds of that figure, we infer that it requires half entirely its area in addition to cover it. It is easily demonstrated also that any two equal rectilineal figures may, by resolving them into parts, be applied by superposition one above the other, so as entirely to agree in quantity.

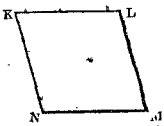


Fig. 666.

A parallelogram is bisected by each of its diagonals, for the triangles into which it is divided are equal to one another: and, consequently, if one angle of a parallelogram be a right angle, all its angles will be right angles. Hence we learn that a rhombus has all its sides equal to one another; that a rectangle has all its angles right angles; and that a square has all its sides equal, and all its angles right angles.

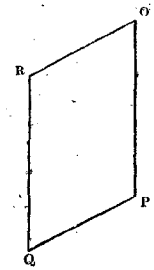


Fig. 667.

Euclid has clearly shown that the opposite sides and angles of parallelograms are equal, and that their diagonals bisect one another; and, conversely, if in any quadrilateral figure, the opposite sides be equal, or if the opposite angles be equal, or if the diagonals bisect one another, that quadrilateral shall be a parallelogram. The same writer has also proved that the complements of the parallelograms which are about the diagonals of any parallelogram are equal to one another.

A Rhombus has its four sides equal, but not at right angles, as K L M N.

The rhombus has the peculiar property of its diagonals crossing each other at right angles; and therefore whenever a quadrilateral has all its sides equal, or its diagonals bisect one another at right angles, it is a rhombus.

A Rhomboid has its opposite sides and angles equal, as O P Q R, without being equilateral or rectangular. The diagonals of all quadrilaterals are straight lines, which join the opposite angles, and consequently would divide the figure into four triangles.

A Trapezium is any other figure whose opposite four sides are not parallel, as A B C D.

A Scalene Trapezium has two of its sides parallel, but its four sides unequal, as E F G H.

A Rectangular Trapezium has two of its sides parallel, and two right angles, as I K L M.

An Irregular Trapezium has none of its sides parallel, as P Q N O.

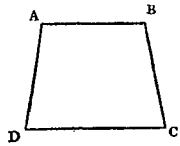


Fig. 668.

When one pair of opposite sides, as in the figure A B C D, are parallel, it is called a *Trapezoid*, and among the remarkable elementary properties of this trapezium are the following. The sum of any three sides is greater than the fourth side: the sum of the squares of the diagonals is equal to the sum of the squares of the sides, and four times the square of the line joining the middle points of the diagonals. The lines joining the middle points of the sides form a parallelogram; and if the figure can be inscribed within a circle, the sum of each pair of opposite angles in two right angles, and the sum of the rectangles of each pair of opposite sides, are equal to the rectangle of the diagonals.

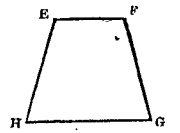


Fig. 669.

When a diagonal is drawn in a parallelogram, and two other right lines parallel with the sides are made to cut it, the two parallelograms which the diagonal does not cut are called the supplements or complements. In the figure R S T Z the parallelograms R X Y and X V T are such.

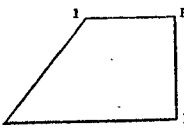


Fig. 670.

Land surveying requires that every plane figure should be resolved into some of the forms we have described, or considered as composed of a certain number of triangles; for computing the area of which it is necessary that we should have the length of at least one side; and when this is ascertained, together with any two of its other parts, those remaining and the area may be computed by the rules of trigonometry.

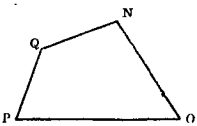


Fig. 671.

Polygons which are regular have their angles equal each to each, because they are contained the same number of times in the same number of right angles, and their sides about the equal angles are to one another in the same ratio.

If the circumference of a circle be divided into any number of equal parts, the chords joining the points of division include a regular polygon inscribed in the circle, and the tangents drawn through those points include a regular polygon of the same number of sides circumscribed about the circle: therefore when we have a regular polygon inscribed in a circle, by drawing tangents through the angular points, we can readily construct another on the outside.

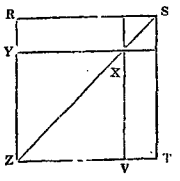


Fig. 672

Pentagon is bounded by five sides, and having within it as many angles; it is called regular when they are all equal, as the figure A.

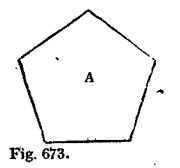


Fig. 673.

In the regular pentagon, if we inscribe within it a triangle, whose base corresponds with one side, and its point that where two opposite sides meet, we shall have an isosceles triangle: in such a triangle we have the angles of the greater double that of the less.

An Irregular Pentagon is where the sides and angles vary, as B.

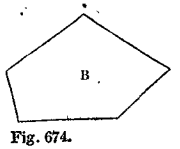


Fig. 674.

Hexagon is a rectilinear figure of six sides and as many equal angles; this is called also irregular when the sides are unequal, as in the figure D.

The side of a regular hexagon is equal to the radius of the circle in which it is inscribed, and it will also be found that the side of a regular decagon is equal to the greater segment of the radius divided medially, and the side square of a regular pentagon is greater than the square of the radius by the side square of a regular decagon inscribed in the same circle. The hexagon is composed of six equilateral triangles, and its figure was much adopted formerly by architects, from the facility which it affords for subdivision.

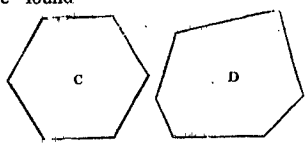


Fig. 675.

Heptagon is bounded by seven sides, E, and as many equal angles; it is called irregular, F, when these are not equal. Heptagonal numbers are those where the difference of the terms of the corresponding arithmetical progression is 5. Thus arithmeticals being called 1, 6, 11, 16, the heptagonals written under them would be 1, 7, 18, 34, &c., the latter being formed by the continual addition of the terms of the first: among the properties of these numbers is one very remarkable, viz. that if any heptagonal number is multiplied by 40, and 9 added to the product, the sum is a square number.

Octagon is bounded by eight sides and angles, as A, and when these vary it is termed an irregular one, as B. It has been found that any regular figure, which has the number of its sides denoted by $2^n + 1$ and prime, may be inscribed in a circle without any other aid than that of plane geometry, that is, by the intersections of the straight line and circle only; and it is clear that by dividing the subtended arcs into two, four, or more equal parts, a regular figure of twice four times, &c., the number of sides of any may be inscribed. An octagon for instance may be drawn by bisecting the arcs which are subtended by the sides of a square.

Nonagon is bounded by nine sides, as C, and has nine equal angles; when irregular, as the figure D, these all vary. This figure, by some geometricians called the *Enneagon*, has not yet had any rule laid down for its construction, and can only be inscribed approximatively.

Decagon has ten equal sides and angles, E; when they vary, as in the figure F, it is not regular.

This figure is the double of the pentagon; and Euclid has shown in his fourth book of the Elements, that the side of a regular decagon is equal to the greater segment of the radius of the circumscribing circle, divided by a medial section, or so that the rectangle contained by the whole radius and one of the parts is equal to the square of the other part.

Undecagon has eleven equal sides and angles, and this may be the form of such a figure as H, which also has eleven sides, arranged neither within a circle nor after any particular form.

This figure, also termed the *endecagon*, has no regular rule laid down for its construction; it can only be set out or inscribed within the circle by approximation.

Duodecagon has twelve sides and angles equal, and is regular when so drawn as H, and irregular as shown in the side figure.

A regular Polygon has all its sides equal, and likewise all its angles equal; and the centre is the same with the common centre of the inscribed and circumscribed circles, and the perpendicular, which is drawn from the centre to any one of the sides, is called the apothem: if any two adjoining angles of a regular polygon be bisected, the intersection of the bisecting lines will be the common centre of two circles, the one circumscribing, the other inscribed in the polygon. The area of a regular polygon is equal to half the rectangle under the perimeter and apothem.

An Equilateral Figure has all its sides equal, as in the square, pentagon, and hexagon, A, B, C.

Those figures of four, five, and six sides when lines are drawn from their several angles to the centres, or when they are inscribed within circles, may have their separate and relative values easily calculated.

Equiangular Figures are those which have their relative angles equal; the figures R S T and V X Y are so, the angle R being equal to the angle V, the angle S to that of Y, and that of T to X.

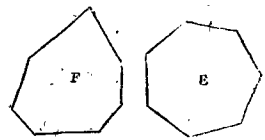


Fig. 676.

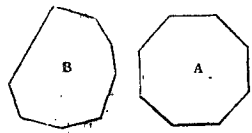


Fig. 677.

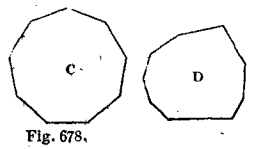


Fig. 678.

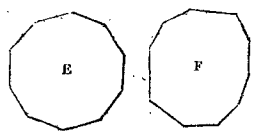


Fig. 679.

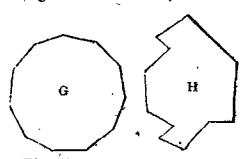


Fig. 680.

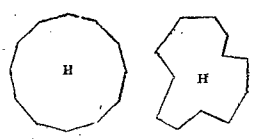


Fig. 681.

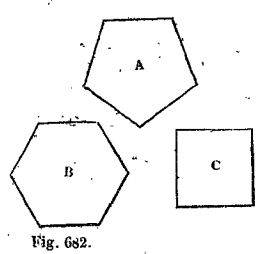


Fig. 682.

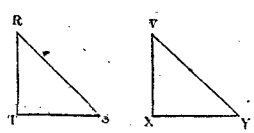


Fig. 683.

Equal Figures contain equal quantities: the square G, for example, contains as much as the parallelogram D.

Equilateral figures are those which have their sides equal to each other, and such, when inscribed in circles, are consequently equiangular, but the converse does not always hold true.

In the square F, by drawing lines across from the divisions made on the respective sides, it may be made into nine equal parts, and if the length of one was set out equal to the divisions in G or D this figure would be in proportion of nine to four when compared with them.

Isoperimetrical figures are such as have equal perimeters or circumferences. Problems which relate to them are extremely difficult of solution, and require a peculiar analysis; as, among curves having the same length, to determine that of which some assigned property is a maximum or a minimum; for example, among those having the same perimeter, to find that which has the greatest area; this constitutes one of the simplest questions of the kind, and the curve to which the property belongs is proved by elementary geometry to be a circle.

In the figure G, the circumference equals the three sides of that shown at E, as well as the four of F in the preceding diagram.

Figures are similar when their relative angles are equal: the side L K is to K M as O N is to N P, and they are said to be similar when their angles and sides exactly agree, as in the figure Q.

Centres are the points in the middle of a figure: A, for example, in the pentagon B C D E F.

Centre, in geometry and mechanics, has a variety of significations, and is numerously applied. The centre of a circle or an ellipse is the middle of any diameter; centre of a curve is the point where two diameters intersect each other; and in mechanics we have to treat of the centres of attraction, equilibrium, gravity, oscillation, &c.

The centre of conversion is the point in a body about which it turns when a force is applied to any part of it, or unequal forces to its different parts. A rod, struck at one of its extremities in the direction perpendicular to its length, will turn it round, but there will be one point in it which remains at rest, or about which the other points turn; this is the centre. The point or fulcrum upon which a lever turns is its centre of equilibrium.

The Centre of an irregular figure is that marked by a star in the middle of H I K L M N O P Q R S, or there may be found the centre of each moiety of the figure, as G T, and then the star taken as a mean.

The Point V is the centre of the circle X Z 9 10, it being equidistant from the circumference in every part.

The Foci or centres of an ellipsis are the points by which it is described, as 1 and 2.

The focus of the parabola is a point in the axis, having this property, that a radius drawn from it to any point in the curve makes the same angle with the tangent at that point that the tangent makes with the axis. Hence a ray of light proceeding from the focus, and reflected by the curve, proceeds in a direction parallel to the axis; or, if parallel rays fall on the concave side of a parabola, they are reflected into the focus.

In the ellipse the two foci are situated in the greater axis, at equal distances from the centre, and if from both foci straight lines be drawn to the same point in the circumference, the two lines make equal angles with the tangent at that point: a ray of light, therefore, issuing from the one focus is reflected by the curve into the other. There is a similar property in the hyperbola, but

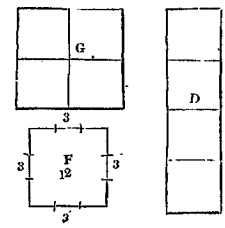


Fig. 684.

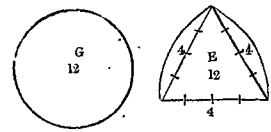


Fig. 685.

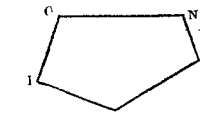


Fig. 686.

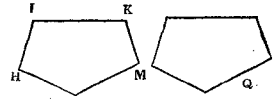


Fig. 687.

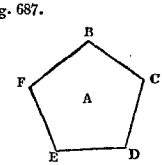


Fig. 688.

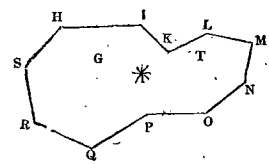


Fig. 689.

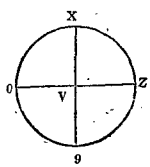


Fig. 690.

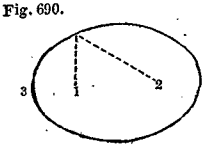


Fig. 691.

with this difference, that one line falls on the concave and the other on the convex: or, the two lines drawn from the foci to any point in the hyperbola, make equal angles with the tangent on its opposite sides.

The Centre of a globe, A Z 10, is that point which is equidistant from every part of its surface. The point Y is the pole of the circle 4.

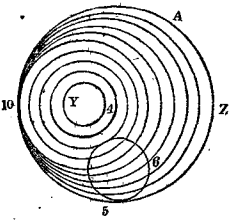


Fig. 692.

Lahire was the first who proposed the globular projection, or the delineation of the terrestrial surface or any part of it on a plane; it is important that this subject should be thoroughly understood. The projection of any circle on the sphere, which does not pass through the eye, is a circle, and circles whose planes pass through the eye are projected into straight lines. The angle made on the surface of the sphere by two circles which cut each other, and the angle made by their projections, is equal.

Gnomonic or central projection is that where the eye is situated at the centre of the sphere, and the plane of projection is a plane which touches the sphere at any point assumed at pleasure: the point of contact is called the principal point, and the projections of all the other points on the sphere are at the extremities of the tangents of the arcs intercepted between them and the principal point. As the tangents increase very rapidly when the arcs exceed 45°, and at 90° become infinite, the central projection cannot be adopted for an entire hemisphere.

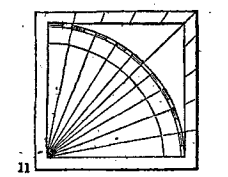


Fig. 693.

The Centre of a geometric square is 11, or the point from which the greater circle is struck.

And the Centre of a rule S is in A, or the pivot on which it turns.

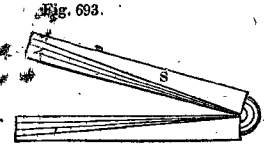


Fig. 694.

The Circumference is that line which bounds a circle whose centre is A.

As we have seen there is a point in a circle, from whence a line may be drawn equidistant around it, and which is the circumference; the rectification of the circle, or the determination of the ratio that the circumference bears to the diameter cannot be expressed in finite numbers. Archimedes in his treatise *De Dimensione Circuli* showed that they were as 7 is to 22, or 113 to 355: De Lagnay found when the diameter was 1, that the circumference was 3·14159265358979323846264338327950288. The areas of all circles are to one another in the ratio of the squares of their diameters, or the area is one-fourth of the circumference: Archimedes makes it nearly in the proportion of 14 to 11: the ratio the area of a circle bears to the square of its diameter has been thus expressed,

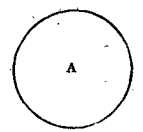


Fig. 695.

$$\frac{2\times4\times4\times6\times6\times8\times\&c.}{3\times3\times5\times5\times7\times7\times\&c.}$$

which is the same as $\frac{8}{9}\times\frac{24}{25}\times\frac{48}{49}\times\&c$; the denominators being the square of the odd numbers, and the numerators differing from the denominators by unity.

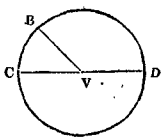


Fig. 696.

Circles have similar circumferences when their diameters or radii are equal, as in those of C D and F G, or V B equal radius V E.

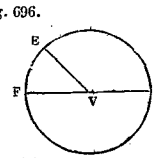


Fig. 697.

The greatest Circumference of a sphere is that which is struck from the pole T as its centre, and which cuts it into two equal parts, the plane passing through the centre H.

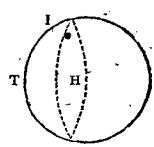


Fig. 698.

The curved surface of a Sphere is equal to the rectangle contained by its versed sine, and the sphere's circumference: for the fluxion of the surface is obviously equal to the rectangle contained by the fluxion of the circumference, and the circumference of the circle of which the radius is the sine; it varies therefore as the sine; but the fluxion of the cosine, or of the versed sine, varies as the sine, consequently the surface varies as the versed sine. Now where the tangent becomes parallel to the axis, the fluxion of the surface becomes equal to the rectangle contained by the sphere's circumference and the fluxion of the versed sine.

The Sphere is divided then into two equal portions, as shown by the sections H of the globe K.

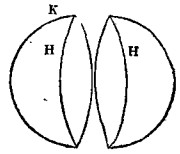


Fig. 699.

The sphere is described by the revolution of a semicircle about its diameter, or it may be defined as a body bounded by a surface of which every point is equally distant from the centre. The curve surface of either of these zones or half globes is equal to twice the area of one of its great circles, or rather of the section made by the plane passing through the centre: the curve surface of a zone or portion contained between two parallel planes is equal to the curved surface of a cylinder of the same height with the height of the zone, or the distance between the planes, and of the same diameter with the sphere, from whence we learn that the whole surface of the sphere is equal to the curved surface of the circumscribing cylinder.

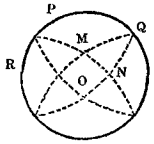


Fig. 700.

The solid content of a globe is equal to that of a cone whose altitude is the radius, and whose base is equal to the surface of the sphere; hence the content of the sphere is one-third of the product of its radius into its surface, and the sphere is also equal to two-thirds of its circumscribing cylinder. Hence the cone, the sphere, and the cylinder, whose diameters and heights are equal, are in the proportions of 1, 2, and 3, or the cylinder is equal to the sphere and cone taken together; the cone is equal to a third part of the cylinder, and the sphere is double the cone.

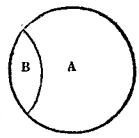


Fig. 701.

In the Globe P the great circle dotted at M, the other at N, and the outer circumference Q R P, are all equal to one another, because the planes by which it is cut pass through its centre.

The globe is by this means cut into four equal parts, and the content of each, as well as their superficies, may be easily ascertained.

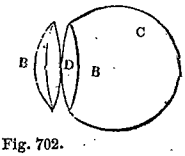


Fig. 702.

A small Circle inscribed on a globe, as that shown at B on the globe A, must be struck from another centre.

Globular projection, or the representation of the boundaries of planes which pass through the globe at right angles with its diameter, belongs more immediately to spherical geometry: a circle whose plane passes through its poles is called the meridian, and which cuts the planes of the equator, and all circles parallel to it at right angles.

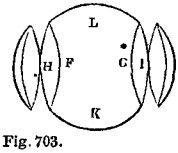


Fig. 703.

The plane of the horizon of any place touches the earth's surface, and divides the whole expanse of the heavens into two hemispheres. The earth's surface was by the ancient astronomers divided into five zones, founded on the different lengths of the longest day, as we proceed from the equator towards either of the poles: these were also denominated climates, and were each of such a breadth that the longest day at the boundary nearest the pole exceeded the longest day at the boundary nearer the equator by a certain space of time, as half an hour or an hour: within the polar circle the climates were supposed of such a breadth as to make the longest day at the opposite sides differ by a month.

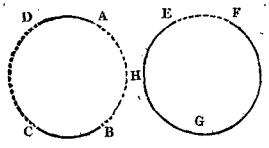


Fig. 704.

The Circle B of the globe C has its centre in the middle of the plane D, and the section made is common to both figures.

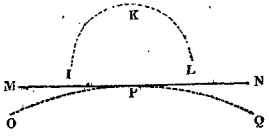


Fig. 705.

Small equal Circles of the same globe have their centres equidistant from its centre. In the globe E the circles F and G are equal to one another, because they are equally distant from the middle of the sphere. H and I are also so in the figure H I K L, and the two portions cut off are equal.

An Arc is that portion of a circle which is less than a quarter of its periphery; the dotted portion E F is an arc of the circle E F G H, as is A D, C B of the other circle drawn in lines.

The Point K of the arc I K L is the summit, and the line M N, as it touches the point P of the arc O Q, is also its summit.

Circles of all sizes are divided into 360 degrees, as F is the centre of the circle B C D, to which they all radiate.

Degrees are divisions which may be shown by right or curved lines, and are here drawn on the circumference of the circle E D C, as well as on the parallelogram, A D L C B K.

By geometricians degrees are understood to be the 360th part of the circumference of a circle, or of four right angles: each of these degrees is divided into 60 minutes, and each minute into 60 seconds, and we find such a division recognised by the ancients. The Chinese divide the circle into $365\frac{1}{4}$ parts, so that the sun daily describes one of these degrees.

The French mathematicians in some instances divide the quadrant or right angle into 100 degrees, and each degree into an hundred minutes, which suits better their decimal method of computation. A degree of latitude is understood to be that distance an observer must advance along the meridian on the surface of the earth to the north or south, in order to produce a variation of one degree in the altitude of the pole; the exact measurement of one of these degrees has been a study of the greatest interest, as by it is ascertained the dimensions of the globe itself.

At the present day this problem has acquired greater importance, in consequence of the discovery of the earth's ellipticity; for it is by the comparison of the lengths of the meridional degrees at different latitudes, that we are enabled to ascertain accurately its true figure.

The great irregularities of the surface of the earth render it difficult, but as the length of a degree depends on the radius of the circle on which it is measured, it will readily appear that the terrestrial degrees at different places, if measured on the external surface, must be unequal. To obviate this, and to reduce all the degrees to the same radius, the surface of the sea is supposed to be continued all round under the continents, and to this surface or level all the measurements are made to refer. The principle adopted is the following: two stations being assumed on the same or nearly the same meridian, the distance between them must be found with great exactness in feet or yards; this being done, the latitude of each of the stations is then determined, the difference of the two latitudes being the length of the celestial arc intercepted between the two stations, and by comparing this with the terrestrial measure, the number of yards or feet corresponding to a degree is known.

An error of a second made in the measurement of the celestial arc corresponds to 100 feet on the ground, so that great nicety of observation is required before it can be ascertained with precision.

From measurements made at various stations, the dimensions and ellipticity of the earth are found to be,

	Feet.	Miles.
Equatorial diameter - -	41,843,330 =	7924·87
Polar ditto - -	41,704,788 =	7898·63
Difference of diameters -	138,542 =	26·24

A Circle is a plane bounded by a single line, called its circumference: the area dotted is a plane so circumscribed by a line A B C D struck from the centre E, and equal circles are those struck from similar radii, as H N I and F L G.

A Semicircle always contains 180 degrees, and is divided, as O P Q.

A Protractor is such a figure, and used to set out degrees: its simplest form is a semicircular limb of metal

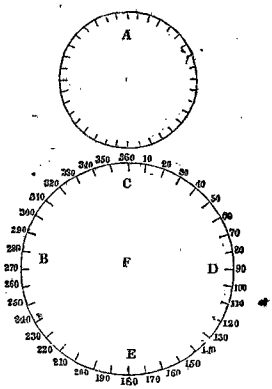


Fig. 706.

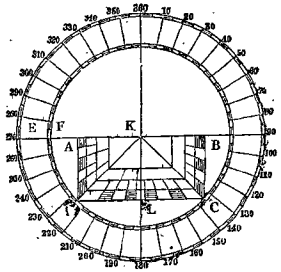


Fig. 707.

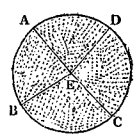


Fig. 708.

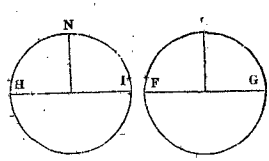


Fig. 709.

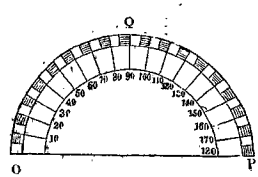


Fig. 710.

divided into 180 degrees, and subtended by a diameter, in the middle of which is a notch to mark the centre: when this notch is placed at the angle of any figure, and the diameter laid along a given straight line, an angle of any number of degrees may be marked off.

For complicated or large surveys the protractor is in the form of the entire circle, having its rim connected with the centre by four radial bars; over the centre is a disc of glass, on which two lines are drawn, crossing each other at right angles, their centre of intersection denoting that of the instrument. Round the centre, and concentric with the circle, is fitted a collar, which carries two arms; one of these has a vernier at its extremity adapted to the divided circle, and the other a milled head, which turns a pinion, working in a toothed rack round the exterior edge of the instrument. The rack and pinion give motion to the arms, each of which carries a fine steel pricker, which is pressed down when the protractor is placed in its required position.

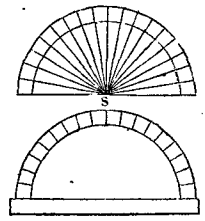


Fig. 711.

The Quadrant contains 90 degrees, and is divided as shown at A B C. This instrument, when attached to an artificial globe, is made of a thin pliable slip of brass, which when applied to its surface serves as a scale for measuring distances between points in degrees: it is graduated into minutes and seconds, and at one end is a nutt furnished with a screw, by which it can be attached to the brass meridian of the globe at any point. This point being placed in the zenith, and the quadrant applied to the globe, its zero coincides with the horizon, and consequently the altitude of any point along its graduated edge is indicated by the corresponding division.

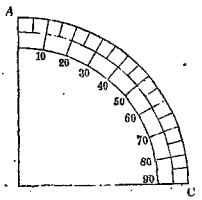


Fig. 712.

A Segment is a less portion, as D E F G. The segment of a circle is a part of the area comprised between an arc and its chord, and segments of different circles are said to be similar when their arcs have the same ratio to the circumference of their respective circles, or when they contain the same number of degrees.

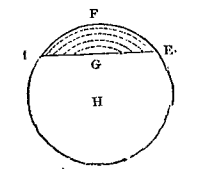


Fig. 713.

A Sector is that portion which by two right lines passing through the centre, as K I, L I in the figure V N. A small sector is indicated by the dotted portion M, and the greater sector by N.

Such a figure is a portion of the area of a circle, bounded by two radii and the intercepted arc: sectors of different circles are said to be similar when the sides or radii include equal angles. The area of a sector is equal to that of a triangle whose base is equal to the length of the contained arc, and altitude equal to the radius of the circle.

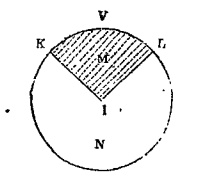


Fig. 714.

Cylindrical Ring is bounded by two circles, and void in the middle, as Q O: its section, when solid, is that of a circle, the area of which multiplied by the length of its diameter gives its contents.

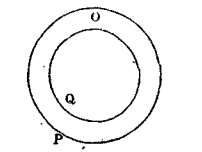


Fig. 715.

Ovals have both a long and short diameter, which divide them into four equal parts: the line C E is the conjugate and B D the transverse diameters: F, F, are the foci.

The Oval or Ellipse somewhat resembles the transverse section of an egg, and a variety of forms are given to it: it is produced by cutting the cone by a plane passing obliquely through its opposite sides. The name of ellipse is derived from one of its properties ascertained, viz. that the squares of the ordinates are less than the rectangles under the respective abscissa and the parameter, or differ from them in defect.

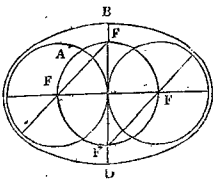


Fig. 716.

The ellipse is the curve in which the planets perform their several revolutions about the sun, and its properties enter into every investigation where physical astronomy is concerned. The curve it forms is defined by means of an

equation between the *radius vector*, which is a line drawn from the focus to the curve, and the angle which it makes with the transverse axis: this is termed the *polar equation* to the ellipse.

It is the property of this figure, that if a circle be described upon either axis, and from any point of that axis an ordinate be drawn, both to the circle and ellipse, then the ordinate of the circle is to the ordinate of the ellipse, as the axis to the other axis. Hence the whole area of the circle is to the whole area of the ellipse in the same proportion, and consequently the area of an ellipse is a mean proportional between the areas of the two circles described upon its transverse and conjugate axes.

The Oval G approaches nearer a circle than that shown at H, the transverse diameter N O being greater than that of P Q.

An Ellipsis may be described by working a thread round the two foci Y Z, and holding it at S, so that it may pass T V X S, and thus form a true oval.

A Parabola is a part of an oval cut off by a straight line, as shown in the figure 4 5 6 7, or at 1 2 3. Spiral lines, as at S, bent in the manner of a volute, are struck from a variety of centres.

The parabola is also formed by the intersection of the cone with a plane parallel to one of its sides, and the term is applied to all algebraic curves of a higher order determined by an equation of the form $y^{m+n} = a^m x^n$. The curve whose equation is $y^3 = a^2 x$ is called the cubical parabola, and that which has for its equation $y = ax^2$, the semi-cubical parabola; this latter curve was the first that was rectified or found equal in length to an assignable straight line.

A figure is said to be inscribed within another when it is bounded, as that of the triangle D E F is by the lines A B C.

It is extremely useful at times to bound a regular as well as an irregular figure within another whose dimensions are known or can be easily computed: in an early Italian edition of Vitruvius, we see the sections of the cathedral of Milan covered entirely with equilateral triangles, for the purpose of accurately calculating its quantity: our freemasons, particularly those who were not thoroughly skilled in computation, could not adopt a more simple means of ascertaining the area of a body than by applying an equilateral triangle to it; six such would form a hexagon, as the four in the cut do that of the triangle of similar sides; this figure is capable of subdivision as well as multiplication, and presuming that the base of a pillar was comprised within any such form, the proportion of its relative parts could be easily computed. Bounding an irregular figure with a parallelogram, and afterwards dividing it into a number of equilateral triangles, its area could be obtained, and with as much precision as by numbers.

The Parallelogram L M N O has inscribed within it the irregular figure H I K.

The Circle may have inscribed within it the *square* P Q S R.

In computing the relative areas of the two figures, we have to consider only that the diameter of the circle is the same as the diagonal of the square; to obtain which we have to square two of the sides and add them together, and then extract the square root, which will be the diameter of the circumscribing circle: when the square is formed on the outside of the circle, then the side of the square is the same as the diameter, and their areas may be easily found by the ordinary rules.

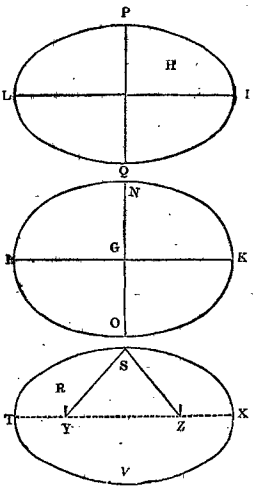


Fig. 717.

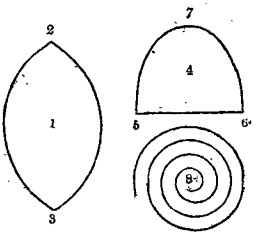


Fig. 718.

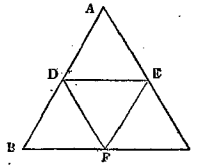


Fig. 719.

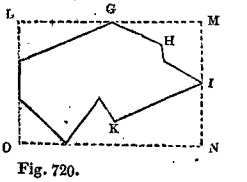


Fig. 720.

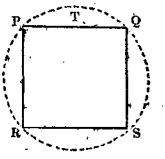


Fig. 721.

The Circle X is inscribed within the *pentagon* 1 2 3 4 5, whose sides are each the base of an isosceles triangle, the property of which is to have each of its angles at the base double that at the vertex; and if any two adjoining angles of a regular polygon be bisected, the intersection of the bisecting lines will be the common centre of the two circles, the one within, and the other circumscribing the polygon.

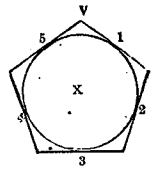


Fig. 722.

The regular polygons, which have the same number of sides, are similar figures; for their angles are equal, each to each, because they are contained the same number of times in the same number of right angles, and their sides about the equal angles are to one another in the same ratio: it will also be evident that the area of a regular polygon is equal to half the rectangle under its perimeter and apothem, which is a perpendicular let fall from the centre to the middle of one of the sides; therefore the sum of the sides multiplied by the length of the apothem will be the area.

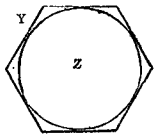


Fig. 723.

When the pentagon, hexagon, or heptagon, or either of them, are formed into triangles uniting in the centre, those must have equal bases and equal altitudes, and consequently are equal one to another; and whatever the shape of the polygon, it must contain as many of these triangles as it has sides, therefore it must be equal to half the rectangle under the perimeter and apothem.

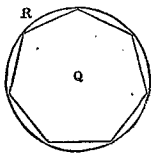


Fig. 724.

The Circle Z is inscribed within the *hexagon* Y.

The Circle B contains inscribed within it a regular *heptagon*.

The Axis is the straight line, real or imaginary, about which a body turns, in which sense it is sometimes called the axis of rotation or of oscillation, according to the motion of the body: it is, however, a straight line about which the parts of a figure are symmetrically disposed.

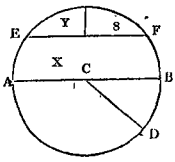


Fig. 725.

The *axis in peritrochio* is one of the five mechanical powers, consisting of a peritrochium or wheel fixed immovably to an axle, so that both turn together round the axis of motion. The power is applied to the circumference, and the weight raised by the rope is wound round the axle: the power gained is the same as that gained by the lever, the longer arm of which is equal to the radius of the wheel, and the shorter equal to the radius of the axle.

The Axis of a Circle is a right line, A B, drawn through the centre C, so as to divide X into two equal parts: E F is the chord, and C D the radius.

The Axis of a Globe is a line passing through its centre I, on which it can move as on two pivots.

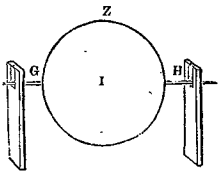


Fig. 726.

Axis of a Cylinder is the line 4 7 passing through its middle vertically, and round which the plane 4 5 6 7 may traverse to generate the figure.

The axis of a column or frustum of a cone is a straight line drawn through its centre, and in the middle of its solid mass: all weight placed upon it should have regard to its true position.

The straight line which divides a conic section symmetrically is called the axis: in the ellipse and hyperbola the axis cuts the curve in two points, which are termed the principal vertices of the ellipse or hyperbola: and a straight line intercepted between them is called the principal diameter or transverse axis.

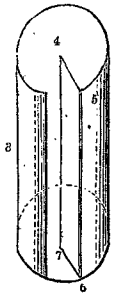


Fig. 727.

The axis of any circle of the sphere is that diameter which is perpendicular to the plane of the circle; its extremities are called the poles.

It is therefore evident that parallel circles have the same axis and poles, for a straight line which is perpendicular to one of two parallel planes is perpendicular to the other likewise: it may also be observed that two parallel circles cannot both of them pass through the centre of the sphere, or they cannot both be great circles of the sphere.

Axis of revolution may be considered that straight line about which the figure revolves.

The Axis of the Ellipsis M is shown at KL. If a moving or generating circle roll along the concave circumference of a fixed circle in the same plane, and the radius of the former be half that of the latter, any given point in the plane of the generating circle within or without it will describe an ellipse; such a curve has been proved to be an epicycloid; when the circle revolves on the inside of the circumference, the curve is sometimes called the hypocycloid. The revolving circle is the generating circle, the circle on which the revolution is performed the fundamental circle, and the portion of the fundamental circle on which the epicycloid rests is the base.

The Axis of the Parabola P is the perpendicular line N O, which falls upon the line Q R.

The Axes of Spheroids are the two lines which cross at right angles, T V being that which is horizontal.

Solids have length, breadth, and thickness. The mass A has length from E to C, breadth from B to D, and thickness from D to E.

The boundaries of solids are surfaces, and all the regular solids are terminated by regular and equal planes; they are five in number, as the tetraedron, the hexaedron, the octaedron, the dodecaedron, and the icosaedron; these are also called Platonic bodies, on account of their being treated of and described by Plato: besides these five there can be no other solids bounded by like equal and regular plane figures, and whose solid angles are all equal: three of these, as the tetraedron, octaedron, and icosaedron, are contained by equilateral triangles; one, viz. the cube or hexaedron by squares, and the other, the dodecaedron, by pentagons. The sphere may be inscribed in either of these, as may also another around or circumscribing it, the common centre of which may be found by bisecting any three of the *dihedral* angles, or by bisecting any three of the edges by planes at right angles with them.

The solid content of any regular polyedron is equal to one-third of the product of its convex surface and apothem, which is the radius of the inscribed sphere.

The regular polyedrons of 6, 8, 12, and 20 faces, have for every face a face opposite and parallel to it, and the opposite edges of those faces likewise parallel; also the straight line which joins two opposite angles passes through the centre of the polyedron: any one of them may be inscribed in a regular polyedron which has a greater number of faces, by taking for its vertices certain of the vertices of the latter, or of the centres of its faces, or of the middle points of its edges.

Similar and equal bodies are those which have all these dimensions of one size, the square O K L and P M N being the same in both, as well as the other sides.

In the *Cube* A the sides B C D are all equal. The hexaedron or cube has six faces, eight solid angles, and twelve edges; the centres of its faces are the vertices of an inscribed regular octaedron; four of its vertices are the vertices of an inscribed octaedron; its adjoining faces are at right angles to each other, and the diameter of a circumscribed sphere is to the edge as the hypothenuse to the lesser side of a right-angled triangle whose sides are as the side and diagonal of a square. The diameter of the inscribed sphere is equal to the edge of the cube.

The *Sphere* has its surface represented by F. As a line according to Euclid is generated by the motion of a point, so a surface is generated by the motion of a line: if the generating line be a straight line, and move, subject to the condition of having always two consecutive positions in the same plane, the surface generated is developable, and can be stretched out on a plane, as that of a cylinder.

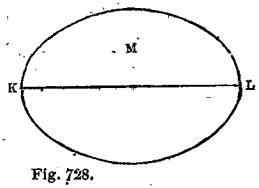


Fig. 728.

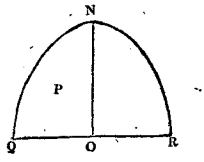


Fig. 729.

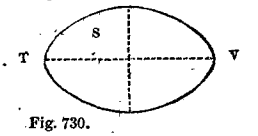


Fig. 730.

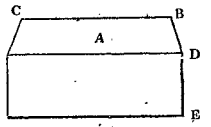


Fig. 731.

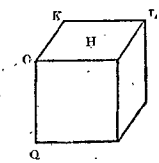


Fig. 732.

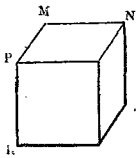


Fig. 733.

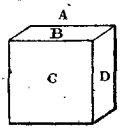


Fig. 734.

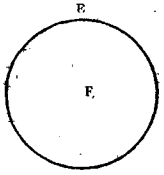


Fig. 735.

The Column G has a circular plane at top and bottom and a cylindrical surface; the irregular figure P is bounded by numerous planes running through Q R S, &c.

To draw accurately such figures, it is necessary to intersect them by planes in a vertical as well as in a horizontal direction: the form P indicates the taste which prevailed in the time of Louis XIV., and which took precedence over the simple shaft previously in use; to ascertain the quantity or weight of such irregular figures the greatest care in their measurement is required.

The difference between the diameters at O and N in the column H I is termed its diminution, and the proportions which govern this in architecture should always be drawn from a study of nature. Smeaton, in preferring the trunk of the oak for his model of the Eddystone lighthouse to the column, showed that he had thought well on the subject, and by adopting the curve line for its section, he produced less resistance to the waves as they rose up its sides: where columns carry weights they must be proportioned to the load, and many writers have urged that eight or nine diameters is as much as should at any time be depended upon for stone or timber; when used as posts the ancients varied their marble columns from four to ten diameters in height, but on no occasion do they appear to load them, when applied to temples, beyond their own weight.

K is an irregular *cylinder*, hollowed in the extent of its height, and formed of different horizontal planes.

The contents of such forms are not very easily obtained, to acquire which a variety of dimensions are necessary: to model them the turning lathe is employed: their curvature can thus be fashioned to the purposes for which they are intended.

A Cylinder has three superficies, formed by a rectangular parallelogram; the solid A is generated by turning the parallelogram Z B C on its axis B C.

The cylinder is a solid figure, the surface of which is partly plane and partly curved, the plane portions being two equal and parallel circles, and the curved portion such that any point being taken in the circumference of either circle, the straight line which is drawn through it, parallel to the line joining their centres, lies wholly in the surface.

The base of a cylinder is the circular ends R and S, that at Q is shown in perspective.

Wherever a cylinder is made use of, either for support or as a gudgeon attached to machinery, we must recollect that its stiffness, when compared to that of its circumscribing prism, is as three times its mass to four times that of the prism. When a cylinder is compared with a prism of the same length and weight, its vibrations, according to Dr. Young, will be less frequent, in the ratio of 300 to 307, or nearly of 43 to 44: then it may be said that the stiffness of a cylinder is to that of its circumscribing prism, as three times the bulk of the cylinder to four times that of the prism; the authority before cited also observes that the force of each stratum of the cylinder may be considered as acting on a lever, of which the length is equal to its distance x from the axis, for though there is no fixed fulcrum at the axis, yet the whole force is exactly the same as if such a fulcrum were placed there, since the opposite actions of the opposite parts would remove all pressure from the fulcrums; the tension of each stratum being also as the distance x, and the breadth being called $2y$, the fluxion of the force on either side of the axis will be $2x^2y\dot{x}$, while that of the force of the prism is $2x^2\dot{x}$ and its fluent $\frac{2}{3}x^3$. But the fluent of $2x^2y\dot{x}$, or $2\sqrt{(1-xx)}\ x^2\dot{x}$, calling the radius unity, is $\frac{1}{2}(z-y^2x)$, z being the area of the portion of the section included between the stratum and the axis, of which the fluxion is $y\dot{x}$, for the fluxion of $\dot{z}-y^2\dot{x}$ is $y\dot{x}-y^3\dot{x}-3y^2x\dot{y}=y\dot{x}^2\dot{x}-$

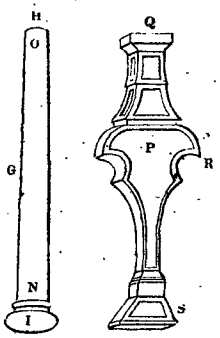


Fig. 736.

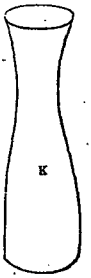


Fig. 737.

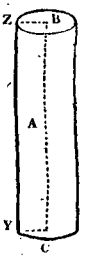
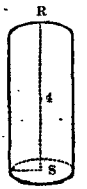


Fig. 738.



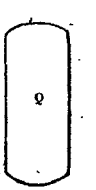


Fig. 739.

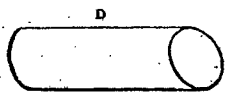


Fig. 740.

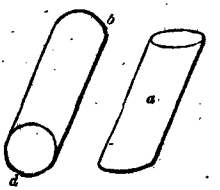


Fig. 741.

$3y^2\dot{x} - \frac{x\dot{x}}{y} = y\dot{x}^2 + 3yx^2\dot{x} = 4yx^3\dot{x}$, and when $x = 1$ and $y = 0$ the fluent becomes $\frac{1}{4}z$, while the force of the prism is expressed by $\frac{2}{3}$.

When the ends of a cylinder are not parallel it is an irregular figure, and it is said to be inclined when placed on one of its ends which is cut in a plane out of right angles with its lengths.

Ballusters are a species of cylinder, which usually are made to swell in the middle; that as I has additional strength to that shown at E, the diameter at F being the same as at its base H.

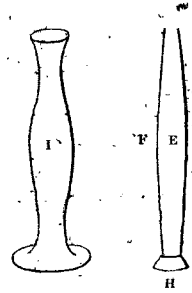


Fig. 742.

A regular Polyedron has all its faces or planes equal, as A. The apothem of such a figure is a perpendicular drawn from the centre to any one of the faces, and is equal to the radius of the inscribed sphere. Cubes, or cubic numbers, are those formed by the multiplication of any number into twice itself, thus 8 and 27 are cubes, the first being equal to $2 \times 2 \times 2$, and the second to $3 \times 3 \times 3$: the number thus produced by multiplication is called its *power*, and the original *number* its root; this is called the square root if the power is square, and the cube root when the power is a cube. These powers are distinguished from one another by the number of times that the given number has been multiplied by itself: the square is called the second power, the cube the third power, and when multiplied again the fourth power, or biquadrate. The first, second, third, fourth, and fifth powers of 10, are 100, 1000, 10,000, 100,000, &c, which in algebra may be represented by a, aa, aaa, $aaaa$, $aaaaa$, or a^{100} when a is raised to the hundredth power, a^3 when a is cubed, and a^4, a^5, &c. when raised to the fourth or fifth powers: such terms are also in geometric progression, because each term is once greater than the preceding.

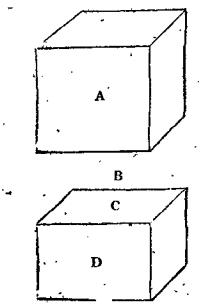


Fig. 743.

Vitruvius informs us that the ancients called 10 a perfect number, but that mathematicians, on the other hand, preferred 6, the number of sides of the cube; its divisors equal its number, for a sixth part is 1, a third 2, a half 3, two-thirds 4, &c.

An irregular cube has them unequal, as those of C D in the figure B.

A Pyramid is bounded by many planes, and terminating at a point, as in those at G and E. They are called pyramids from the resemblance they bear to a spire of flame; but the etymology of the term is perhaps derivable from the Egyptian words, which signify the separating or setting apart from common use, which was the case with such buildings: the word pyramid, therefore, may denote a sacred fane or place set apart for some religious use.

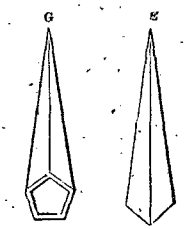


Fig. 744.

In geometry a pyramid is a solid contained by a plane polygonal base and other planes meeting in a point, which is called the vertex; the planes which meet in the vertex are called the sides, which are all triangles, and the slant height is the length of one of these sides measured from the point to the middle of one side of its base: every pyramid is equivalent to one third of a prism having the same base and altitude; consequently those which have similar bases and altitudes are equal: the solid content is found by multiplying the area of its base by one-third of its perpendicular height.

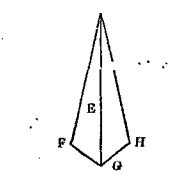


Fig. 745.

The base of a pyramid is the plane opposite to its apex or points, or the side on which it rests; F G H is the base of the figure E.

F, H, M, are pyramids with square bases, and the figure M is usually designated, when the top H is removed, the frustum: when a pyramid is cut by a plane parallel to its base, the frustum, as M, which is the part comprehended between the base and the section, is equal to the sum of three

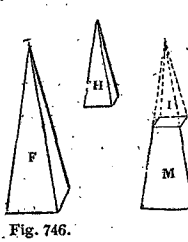


Fig. 746.

pyramids, having for their common altitude that of the frustum, and of which the bases are respectively the lower base of the frustum, the upper base of the frustum, and a mean proportional between them.

A truncated Body is that of a pyramid, where L is so called, when the top M is broken off.

Obelisks are of this form, and may have any number of faces, one of which is a triangle or other rectilineal figure, and the rest triangles which have a common vertex, and for their bases the sides of the first triangle or rectilineal figure: the altitude of such pyramids is the perpendicular distance of the vertex from the base, and the truncated pyramid is said to be triangular, quadrilateral, or pentagonal, according to the figure of its base. When the pyramid has a part of its summit cut off by a plane parallel to its base, the part next the base is called the *frustum*, and sometimes a truncated pyramid.

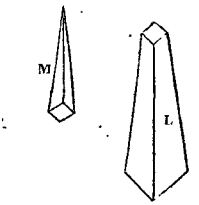


Fig. 747.

A Prism is a solid composed of many planes, of which the two opposite are equal; K, T, and S are instances of triangular, square, and hexagonal prisms.

The prism is a solid contained by planes, of which two that are opposite are equal, similar and parallel, and all the rest are parallelograms. A right prism has its sides perpendicular to its ends; an oblique prism is that of which the sides are oblique to the ends.

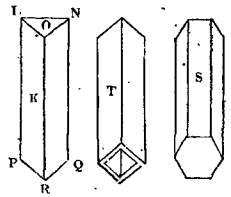


Fig. 748.

Tetraedron has four equal sides, formed by four equilateral triangles, H and I, or it is a triangular pyramid having four equal and equilateral faces, which are the least number possible for a solid. If we assume $a =$ the linear edge, $b =$ the whole superficies, $c =$ to the solid content, $r =$ the radius of the inscribed sphere, $R =$ the radius of the circumscribed sphere, then the following relations hold true,

$$a = 2r\sqrt{6},\ b = 24r^2\sqrt{3},\ c = 8r^3\sqrt{3},\ R = 3r.$$

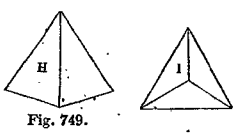


Fig. 749.

Hexaedron is a solid which is bounded by six equal sides, as E and A. This is one of the five regular or Platonic solids, the whole surface of which is equal to twenty-four times the square of the radius of the inscribed sphere, and to eight times the square of the radius of the circumscribed sphere, and its solid content is eight times the cube of the inscribed sphere.

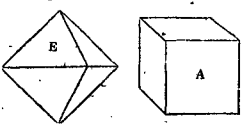


Fig. 750.

Dodecaedron is composed of twelve equal, equilateral, and equiangular pentagons, as the figure F.

The surface of the dodecaedron is found by multiplying the square of its side or linear edge into the number 20·64578, and its solidity by multiplying the cube of its side by 7·66312.

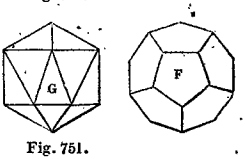


Fig. 751.

Icosaedron is a solid composed by twenty equal, equilateral, and equiangular triangles, as the figure G, and may be regarded as formed of twenty equal and similar triangular pyramids, whose vertices all meet at the same point; hence the content of one of these pyramids multiplied by 20, gives the whole content of the icosaedron.

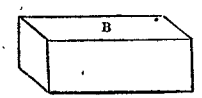


Fig. 752.

Parallelopipedon is a solid composed of six plane quadrangles, of which the opposite sides are parallel, four of which are equal to one another.

All the faces of one of the above named solids cannot be seen at the same time; in the cube A, we can from the point X only see the three faces A, D, and C, and the eye may be so placed above it that only the top face may be seen.

In the representation of the several solids, it is necessary that we should attend to some rules, and that they should always be drawn, either as they appear to the eye, or according to a recognised scale. Isometrical perspective gives us, as we shall hereafter see, such a method of showing the various sides of a cube or other figure, and ascertaining from a scale its relative dimensions. When it is required that a solid should be projected in the plane of a picture with its

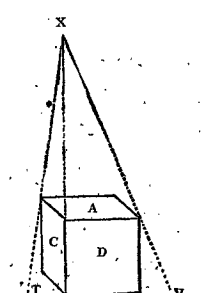


Fig. 753.

actual dimensions, we may obtain the requisite measures from the properties of similar triangles; for instance, to find the position of the image of either of the right lines in the cube, we must determine the point in which a line parallel to it, passing through the place of the eye, cuts the plane of the picture; this, which is called the vanishing point, is shown at X, and all the lines which are under the same parallel will tend to it; when the lines are, however, parallel with the plane of the picture, the distance of their vanishing point becomes infinite, as we shall see when treating of the laws of perspective. In treating diagrams, geometricians usually make all lines which are on the return of a cube, or which represent its sides, tend to one point, and draw the face in front, as D, perfectly square.

When a cube is represented with its sides equal, it is said to be geometrically drawn, but when shown as at K it is in perspective.

A Sphere is a body comprised within a single superficies, in which all the lines drawn from a central point equal one another.

L M N O is an hemisphere or half globe; a segment either less than a portion cut off, as at Q, or greater, as that part of the sphere at R.

The zone is a portion taken out of the middle, as shown at S.

The sector of a sphere has a portion of the outer surface, and terminates in a point as at T.

The globe R, when cut in two, has the parts or planes shown as at T, V, which are called its sections, and S is an hemisphere.

B is an armillary sphere, and used by astronomers to show the motion of the earth, and the relative position of the sun, moon, and stars, &c. This is an ancient astronomical machine composed of an assemblage of hoops or circles, representing the different circles of the system of the world, as the equator, the ecliptic, the *colures*, &c., arranged in their regular position.

D shows the mounting of the sphere used to represent the earth, which is usually represented as round, or a true globe; this was inferred from the figure of its shadow, as seen on the moon's disc in lunar eclipses. The hypothesis of its being a true sphere is sufficient to explain the general appearance of the heavens as seen from different points of its surface; Eratosthenes, upwards of 2000 years ago, made the attempt to ascertain its diameter: he knew that on the day of the summer solstice the sun illuminated the bottom of a well at Syené; at the same instant he observed at Alexandria that the sun was 7° 12′ from the zenith, and it was supposed that Syené was due south from that place, and, therefore, that both were under the same meridian. Having determined the distance between the two places to be 5000 stadia, and accurately measured the sun's altitude, he found the earth's circumference to be 250,000 stadia; this method, which is not accurate, was afterwards adopted by many other philosophers.

Artificial globes are used for explaining the rotation of the earth, the latitude and longitude, and the situation of places with respect to each other; they are, however, limited to general explanation: it is often highly necessary for the engineer to determine the meridian, or to draw a meridian line, and this requires the aid of a good telescope, a well-regulated clock, and the sextant, or an instrument for determining the altitude of the sun or star. By the sextant we can determine two instants of time; when the star has the same altitude, the clock will give the interval of time between them, and half this interval will be the time between each observation and the passage of the star over the meridian. If we next day note the time of the

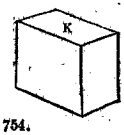


Fig. 754.

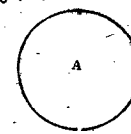


Fig. 755.

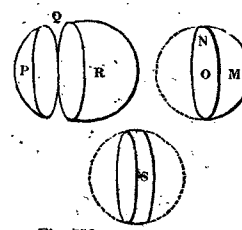


Fig. 756.

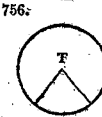


Fig. 757.

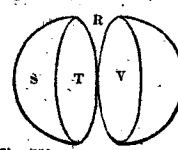


Fig. 758.

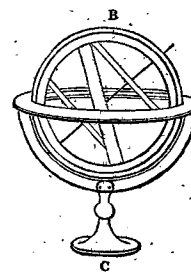


Fig. 759.

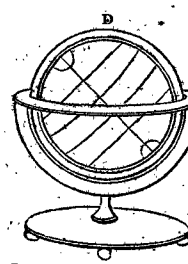


Fig. 760.

clock when the star again attains that altitude, and add to that time the above mentioned half interval, we shall have the time by the clock when the star will be on the meridian; if at that instant a telescope, movable in a vertical plane, be directed to the star, so that in passing the meridian the star may be on the axis of the telescope, the position of the plane of the meridian will be obtained. If a meridian circle pass through the zenith of any place, the arc intercepted between the zenith and the equator is called the *latitude* of that place: assuming this or any other meridian circle that passes through the zenith of any particular place as the first meridian, the arc of the equator intercepted between the first meridian and the meridian circle passing through the zenith of any other place is called the *longitude* of that place: by the zenith is meant the top of the heaven, or vertical point directly over head, or it may be defined as the pole of the horizon, from which it is 90° distant.

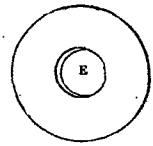


Fig. 761.

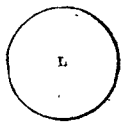


Fig. 762.

When a cavity is made through a globe, as at E, it is said to be pierced.

In the globe L it is comprised over its whole surface; the coating of a sphere is its superficies. In a part of a globe the area of the base or section must be added to that contained over the convex portion to obtain its superficies.

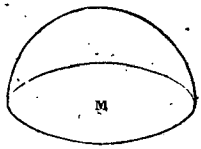


Fig. 763.

In the figure EFGHIK, the upper and lower faces, as well as those of the ends, must be added together to make up the total surface or entire superficies.

And when it contains a cavity in the centre, as a shell, it is a hollow globe or sphere.

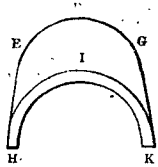


Fig. 764.

A Spheroid is an oblong sphere formed by the turning of an ellipse round its axis: if the generating ellipse revolves about its major axis the spheroid is said to be prolate, and about its minor, oblate.

Supposing $2a$ the axis of revolution, and $2b$ the diameter of the generating ellipse perpendicular to the axis, then the origin of the co-ordinates being at the centre, and x being taken on the semi-axis a, the equation of the spheroid is

$$\frac{x^2}{a^2} + \frac{y^2 + z^2}{b^2} = 1.$$

The solid content of such a figure is equal to two-thirds of its circumscribing cylinder.

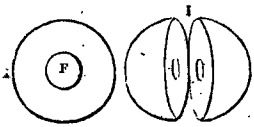


Fig. 765.

A Paraboloid is the half of such a figure, and is described by the revolution of a half parabola round its axis: sometimes the term is used to express the parabolas of the higher orders, and sometimes the solid formed by the rotation of a parabola about its axis, or the parabolic conoid. In the parabola the parameter of its axis is a third proportional to the abscissa and its ordinate. The focus is that point in the axis where the ordinate is equal to the semi-parameter; the diameter is a line within the curve terminated thereby, and is parallel to the axis; an ordinate to any diameter is a line contained by the curve, and that diameter parallel to a tangent at the extremity of the diameter. In a parabola the abscissas are proportional to the squares of their ordinates; and as the parameter of the axis is to the sum of any two ordinates, so is the difference of these ordinates to the difference of their abscissas. The distance between the vertex of the curve and the focus is equal to one-fourth of the parameter; the radius vector is equal to the sum of the distances between the focus and the vertex, and between the ordinate and the vertex.

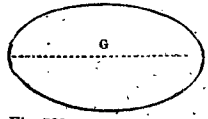


Fig. 766.

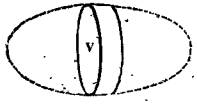


Fig. 767.

The parabolic curve is that which some mathematicians call the curve of equilibrium for an arch, because it sustains a load uniformly when distributed over its length; it should be comprised in the depths of all flat arches, and it is the best form for suspension bridges. It is the curve described by a cannon ball, and by a jet of water when it

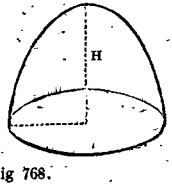


Fig 768.

issues from a hole made in the side of a cistern or reservoir, and it forms the best curve for the reflection of light.

The mouldings found in Greek temples, so worthily admired, are all of this form; they result from the intersection of conic surfaces by planes parallel to the side of the cone in general.

V X is the base of the parabola Y. The parabola is a curve consisting of two similar sides, which may be produced indefinitely, by being drawn in such a manner with regard to the axis passing through the vertex, that the abscissæ are to each other as the squares of the ordinates; so that if the former be 1, 4, 9, the latter will be 1, 2, 3, &c. When a body or projectile is thrown in a horizontal direction, its path through the air will be half of a parabola, whose vertex lies in the point of projection.

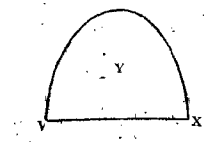


Fig. 769.

When a body is thrown obliquely upwards, its path is that of a complete parabola, whose vertex will be the highest point reached by the body, which ascends one side and descends by the other: if the projectile forms any angle whatever with that of gravity, a body set in motion by these forces will not follow the direction of either of them, but will adopt a middle course proportional to both the forces; the course of the body, which is determined by the laws relative to the parallelogram of forces and the earth's attraction, will be that of a curved line resembling the parabola.

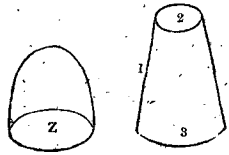


Fig. 770.

The base of a paraboloid, as Z, is its circular end; in the frustum of a cone it is at 3, and the top at 2 shows the base of the part cut off, and 1 the slant height.

In the parabola N O P the superficial content may be obtained by considering it as the portion of an oval.

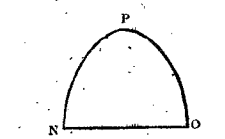


Fig. 771.

A Cone is a body comprised within two superficies, and is formed by revolving a right-angled triangle on its axis, as that at X. So is formed the paraboloid C when one side of the figure is curved.

The base of a cone is the circle on which the figure stands: N O is the slant height.

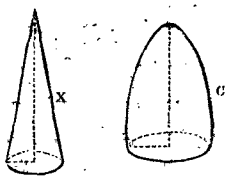


Fig. 772.

If a body be thrown vertically upwards, it will be retarded in an uniform manner, and not arrive either perpendicularly or at the apex of the cone, but will, by the influence of gravity, assume the parabolic curve, which is one of the sections of the cone. This is in consequence of the effect of the projectile force becoming every moment less powerful by the earth's attraction on the ascending body, and which is exactly in the same ratio as it accelerates its descent. The laws which regard the latter are in inverse application; a body will therefore lose its velocity after a certain time, and return to the surface of the earth in precisely the same time as was occupied by its ascent; the projectile force is momentary, and the action of gravity permanent; the motion is consequently a compound one, the forces acting sometimes in the same vertical, and sometimes in an opposite or oblique direction.

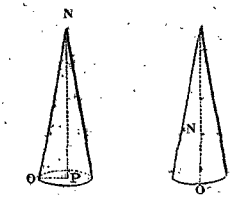


Fig. 773.

When a ball or other body is projected, its force as well as angle may be ascertained by using a spiral steel spring, which may be strained according to various degrees of tension; this spring, placed in a tube, and made movable about a pivot, may be made to act at any required angles by means of a graduated scale.

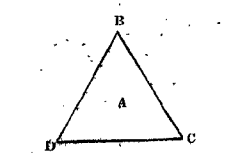


Fig. 774.

The base of an angle is D C: B is the summit of the angle A.

The base of any solid is the side on which it rests: L M is the base of the figure K.

The amount of the weight of such a body is proportional to the mass, the measure of which, estimated by that of some other body which serves as an unit, is termed its absolute weight. Gravity and weight in mechanics always are to each other in the relation of action and re-action.

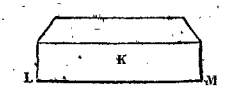


Fig. 775.

The superficies is that which has length and breadth: A B C D in the parallelogram bounds its area, and indicates its quantity.

A B is the boundary of the straight line as C D is of the curved: E F G H are the boundaries of the parallelogram.

Boundaries.—It is curious to observe the principles adopted by the ancient geographers in their description of a country to express its form: Strabo tells us that Spain resembled a hide spread out, and we also learn that Alexandria was in the form of a Macedonian cloak. Britain was represented by them as contained within a triangle, of which the base or longest side was that opposite to Gaul.

The Greeks considered the several continents to be bounded by the sea. The general outline of a country must be obtained before we can accurately estimate its area, and in our descriptions we must notice its boundaries; England, for instance, is bounded on the south by the English Channel, on the east by the German Ocean, on the north by Scotland, on the west by the Irish Sea and St. George's Channel: in mapping a country or an estate, it is necessary that we should remark on the boundary lines, where it touches or comes in contact with the adjoining lands not comprised in our survey: from an accurate map of England and Wales, with its outline properly defined, the area was computed to be 57,960 square miles.

The term England is derived probably from its triangular form: the base of the triangle is a line drawn from the South Foreland in Kent to the Land's End in Cornwall; the eastern side, by a line drawn from Berwick to the South Foreland, and the western or longest side, by a line drawn from Berwick to the Land's End. In the maps which were drawn during the last century there was no approach to the accurate form of either England or Wales, nor was there any attempt made by the surveyors of that time to exhibit the rising ground, mountain chains, or principal features of the country. From such inaccurate surveys we cannot be surprised at the differences which appear in the various calculations of the area which have been made. Sir William Petty estimates the area of England and Wales at 28,000,000 acres, Gregory King 39,000,000, Dr. Halley 39,938,500, Arthur Young 46,916,000, Dr. Beeke 38,498,572, and Mr. M'Culloch at 36,999,680; the latter is much nearer the truth, as the statute acres he has given were deduced from the aggregate measurements of the several counties in England and Wales: of these Wales comprises 4,752,000, and England 32,247,680 acres. It is of the utmost importance that the boundaries of all kingdoms and states should be clearly defined; before this is done, or an outline of their coasts or form is obtained, it is not possible to compute their area, or to lay down a system of taxation or rates that the inhabitants should contribute to the state. The boundaries which relate to a district should also be well defined, as should those which nature has prescribed, as the basin or valley drained by a particular river: sufficient attention has not been paid to this part of the subject of mapping, for all rivers have a limit or boundary, in their drainage of the superfluous waters, and the high ground from which they draw their supply is capable of being defined and having its outline established. In making the surveys for the parishes throughout England this might have been attended to, and the information conveyed would then have been invaluable to the engineer in all his future surveys, and to the government in controlling him.

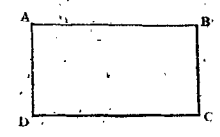


Fig. 776.

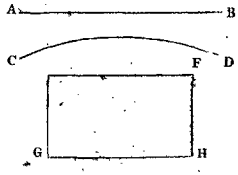


Fig. 777.

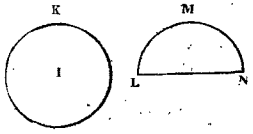


Fig 778.

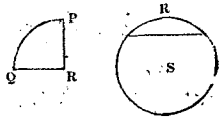


Fig. 779.

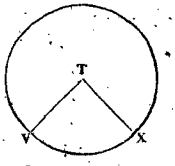


Fig. 780.

Of areas and solids it is not necessary to say any more of their boundaries than that the lines and surfaces which contain them are so called; as, for example, A B is the boundary of the straight line, &c.

L M N is the boundary line of the half circle, as K is that of the whole figure I.

P Q R are the boundaries of the quarter circle, and R is that of the segment cut off S.

When the curved line of a segment is less than half the circumference, as at R, it is the small segment.

The boundaries of a sector are T V X, the radius or lines T V and T X comprising a part of the external circumference.

The boundaries of a vessel of any kind, whether those of a vase, cup, or box, are those surfaces and lines which are visible to the eye; they comprise all within and without, and whatever presents a face.

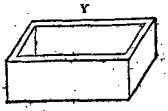


Fig. 781.

Fig. 782.

Zones or *Girdles* are those bands which encompass or surround a sphere, as that between B and D.

G L I, H M K, indicate the zone between F and E: a zone may embrace only a portion of a sphere, as that indicated at C in the two halves, A, A.

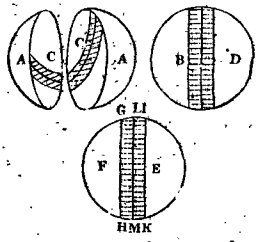


Fig. 783.

The globe is divided into five zones by the two tropics and the two polar circles; that comprised between the tropics is called the torrid, its breadth being 47°, or twice the sun's greatest declination; this is divided into two equal parts by the equator. That zone included between the tropic of Cancer and the arctic circle is called the north temperate zone, and that between the tropic of Capricorn and the antarctic circle the south temperate zone: each of these are in breadth 43°; that portion comprised between the arctic circle and the north pole is the north frigid zone, and that between the antarctic circle and south pole the south frigid zone.

This division of the earth into zones probably arose from the difference observed in the temperature, which is higher in the equatorial regions than in any other part of the earth, in consequence of the sun's rays being more direct; to every point of the earth's surface whose zenith lies between the tropics, the sun is vertical twice in the year: in the polar regions the temperature is lowest, in consequence of the obliquity with which the sun's rays fall, and the length of the winter night. In the countries situated between these two regions there is a medium temperature, increasing as the zenith approaches the nearer of the two tropics, and diminishing as it approaches the nearer of the polar circles.

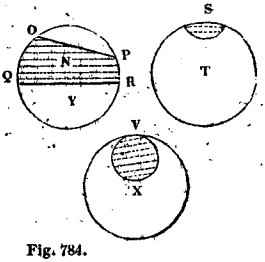


Fig. 784.

Zones are sometimes irregular, as N on the globe Y, the widths of O Q and P R being different.

S is a zone on the globe T, as is V on that of X.

Plans are of various form, as those of A, B, and C: any figure having superficial contents is so designated.

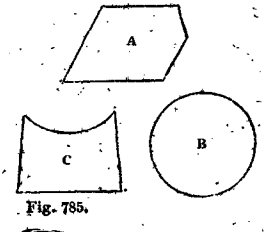


Fig. 785.

The surveyor of land determines by measurement both the boundaries and superficial content of any portion of the earth's surface; the object being to ascertain the content of a single field, or the relative distances and bearings of the various buildings or other objects around or within it. In measuring land, all the lines and surfaces whose contents are to be found are reduced to the same horizontal plane, on the principle that as corn grows vertically, no greater quantity can be produced on the slant side of a hill than would grow on the area which its base covers: when the lines measured are not horizontal, they must be multiplied by the cosines of their respective inclinations to the horizon. When a country is surveyed, or a large geometrical map is to be formed, it is necessary to have regard to the earth's curvature and many other circumstances.

Ichnographic plans, as shown at D, are made use of to exhibit the foundations of the walls of a building, or the arrangements of the several divisions or compartments.

This term, derived from the Greek, signifies a *model*, and the drawing of it: in architecture it usually indicates the ground plan, as of a fortress, garden, or building: when either of these are laid down properly to a scale, any portion, as well as the whole quantity may be estimated, and if the walls or points of supports are distinguished by colour, their proportions with regard to void

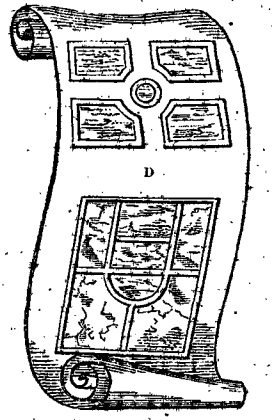


Fig. 786.

may be also calculated; this is an important preliminary before any constructions are commenced, and great accuracy in the drawing is requisite to make the estimates correctly.

An *orthographic plan* shows the extent as well as elevation of the several portions of the building.

A *scenographic plan* represents the whole in perspective.

Vitruvius informs us that architecture depends on fitness and arrangement, and also on proportion, uniformity, consistency, and economy: the first relates to the nice adjustment of the dimensions of the several parts to the whole, as well as to their use. *Ordination* is the word we have rendered into fitness, and in it is comprised the terms we are now using, as Ichnography, Orthography, and Scenography; as the first relates to the plan drawn geometrically, so does the second to the elevation; the last exhibits the front and receding side properly shadowed, the lines being drawn to their proper vanishing points. After such a description as is contained in the author above cited, it is not possible to fancy that the Romans were unacquainted with our method of making designs, and particularly when he further observes that the three systems of preparing them are the result of *thought* and *invention*, the first being an effort of the mind, ever incited by the pleasure attendant on success in compassing an object, whilst the other is the effect of this effort, which shows a new light on things the most recondite, and produces them to answer the intended purpose: such are the ends of arrangement. Proportion is that agreeable harmony which results from one and all parts agreeing with each other and the whole: uniformity is the parity or likeness of the parts to one another; consistency is the result found when the work exhibits a suitable detail, and economy is the due and proper application of the means afforded, and prudently employing it. The second chapter of the first book of Vitruvius should be studied by all who are desirous of becoming civil engineers.

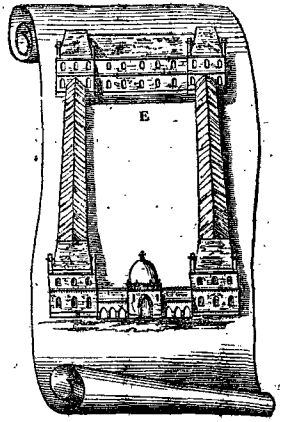


Fig. 787.

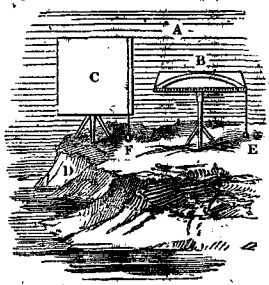


Fig. 788.

Of different sites or situations of planes with regard to the horizon, which is said to be either *sensible* or *rational*; the first is a plane which is a tangent to the earth's surface at the place of the spectator, extended on all sides till it is bounded by the sky; the latter is a plane, parallel to the former, but passing through the centre of the earth. These two terms are only relative, as they vary with the spectator's position; for when his eye is in the plane of the sensible horizon he can only see what is above it, but when it is raised above the horizon he can observe what is beneath it. The *sensible* horizon is therefore properly defined to be the conical surface which has its apex in the eye of the spectator, and embraces the portion of the earth over which the eye can reach; the visual rays, which are tangents to the earth, are situated in this surface, and point below the true sensible horizon, or the rational horizon which is parallel to it; and the angle which a visual ray makes with the plane of the horizon is termed its *dip* or *depression*, and which is easily estimated from the known dimensions of the earth, and the height of the eye above its surface. An inclined plane is that which is neither horizontal nor vertical, but which slopes on the horizon, as the cliff at D.

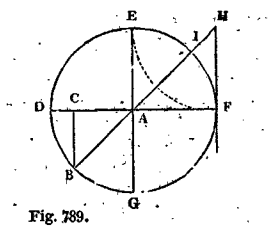


Fig. 789.

A may be considered the true level or the surface of the waters; B is the horizontal plane parallel with A; C is a vertical plane perpendicular to A, or parallel to the plummet let fall at E; D may be called an inclined plane.

Of Sines, Tangents, and Secants.—The sine of any arc of a circle is the straight line drawn from one extremity of the arc perpendicular to the radius, passing through the other extremity. The sine of an arc is the half of the chord of the double arc. The tangent to a curve is a straight line which meets or touches the curve without intersecting it; the arc and its tangent have always a certain relation to each other, and when the one is given in parts of the radius, the other can always be computed by means of an infinite series; the Arabians were the first to introduce tangents into trigonometry, and which render important service in simplifying many calculations. The secant is a straight line drawn from the centre of a circle to one extremity of an arc, and produced until it meets the tangent to the other extremity. The secant of an arc is a third proportional to the

cosine and the radius, hence if the radius be taken as unit, the secant is the reciprocal of the cosine. The cosecant and cosine is the complement of an angle or arc.

The sides of the triangle A B C are sines, because its sides are enclosed in the circle E F G B D, which has for its radius one of the sides A.

A tangent is a right line which falls perpendicularly on the end of the radius, where it touches the circle, as H F: A H is a secant.

To trace a line or any figure on the ground, the engineer is provided with staves or rods of various lengths which enable him to station the holder at any particular point where the observation is required to be made; such a staff or piquet is made use of, with various devices on the point, to set out a straight line through any district that is to be surveyed. Any one stationed at either of the extremities of the line A D could direct others at the intermediate stations F, C, H, B, E, to plant their rods in the direct line; which when set out is to serve as the base or diagonal of a figure, from which the country around is to be mapped or levelled.

Sometimes these piquets have placed upon them boards, either coloured or pierced with holes, or with curved tops, which enable them to be more readily distinguished.

The staves made use of for levelling have a vane which slides up and down with facility, and can readily be lengthened; these are accurately divided in their height into hundredths of a foot, and are alternately coloured black and white: the lines denoting the tenths are drawn through the whole breadth, and every ¼ and ½ foot is further distinguished by one or two conspicuous dots or marks.

Smaller stumps or pins are made use of to mark out the line or figure after the survey is commenced; Q is a form made use of for one description of marks, and P for another.

When the excavator commences his labour, he is generally instructed to leave witnesses of his work in the shape of small cones of earth, by which the depth of his excavation can always be obtained. B is the natural and original level of the man A. At every extreme height as well as depth, these marks should be left for the engineer to make his survey when he is desirous of verifying the quantity of earth which has been removed.

In measuring such an excavation, it is the hole made in the ground that is to be measured, and not the earth removed, and when great depths are taken out, allowances in price are made accordingly; in large excavations the workmen are usually distributed in gangs; one digs, another fills, and a third wheels the earth away: when the distance exceeds twenty yards, a fourth man is employed, a stage being considered that distance. The first man, who has to wheel the earth out of the work, generally has an inclined plane to mount, whilst the second runs his barrow along level ground; when this is the case, the stage or run is limited to a less distance, and when the level is an inclined plane, then the run is extended to twenty-five yards. There is a considerable advantage obtained in dividing the moving of earth into separate stages, but the engineer who has the direction of the

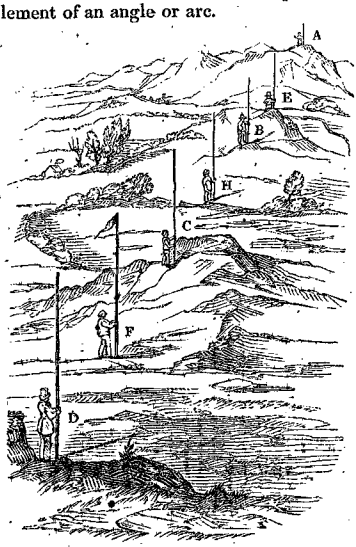


Fig. 790.

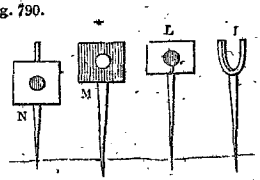


Fig. 791.

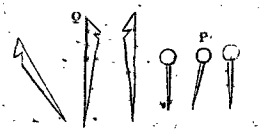


Fig. 792.

Fig. 793.

work should always set them out proportionably, which sometimes is rather a difficult task to perform. As the excavation proceeds it should be measured, as it is expedient that this should be done before any of the marks are obliterated or destroyed, which they are constantly subject to, particularly where horses and carts are employed in any great numbers.

Rules, Sight Vanes, &c. — Rules are required of different lengths and thicknesses, with straight and bevelled edges, either to draw lines on paper in pencil or with ink; but when a line is to be drawn on the ground, it may be done more readily by stretching a line, as at C, from one stump to another.

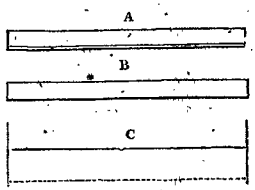


Fig. 794.

Parallel Rules. — There are several kinds in use; the best consists of a single rule with an axis, carrying two small rollers fixed at each extremity: these must be made of precisely equal diameters, and should be as far apart as the length of the rule will permit: an instrument rolling on two such wheels will be moved parallel to any position it was first placed in, and consequently parallels to any line to which its edge is set may be drawn. The edges of the wheels are grooved very truly, to prevent them from slipping instead of rolling, which would affect the parallelism.

The second variety consists of two plain rules connected by two equal pieces of brass turning on centres, and these must be truly parallel, so that in every position the four centres of motion may form a parallelogram: when used, the edge of one being set to any line, the other rule must be firmly held down by the hand, and the first moved till the same edge is brought to where the required parallel to the given line is to be drawn. The faces of these rules are generally provided with scales.

E, D, or any other very long line, may be accurately set out by means of piquets placed at short distances, and making use of an instrument with an eye-hole, as at B, H, and which is made to traverse along the line, and having attached to this instrument a plummet so that its perpendicular may always be maintained; parallel lines may afterwards be drawn in any number. Take also the shortest distance between the point A and the given line D E, by placing one foot of the compasses on the point A, and describing with the other an arc which shall touch the given line D E in the point F, than the interval A F will be the shortest distance from the point A; then with the same distance, from the point G, strike a similar curve, and lines may be thus drawn or set out parallel to each other.

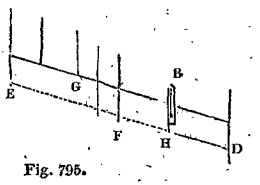


Fig. 795.

To draw through the point A a line parallel to K I, first draw from the point A the line A K, till it touches the right line K I in any point K; from this point A, and with any radius as O P, describe the arc O P, then with the same radius from A strike the arc Q N, and by setting off the same angle from N to Q, as that of O P, and then through Q drawing the line A Q, we have the parallel line required.

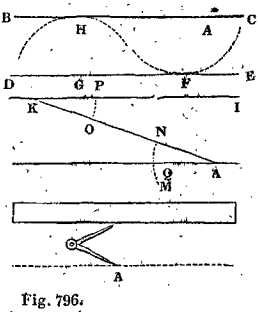


Fig. 796.

Another method may be pursued with a pair of compasses: after a straight edge is laid down, points may be marked at the required distance, through which the line may be afterwards traced.

If through the piquet Q a line parallel to the railing B S is to be drawn, and you then place two piquets at B, S, and with the same length of cord strike two portions of a circle, as at Q T, a line drawn through two other piquets placed at the extremity of this radius will be at once equally distant from the railing and parallel with it.

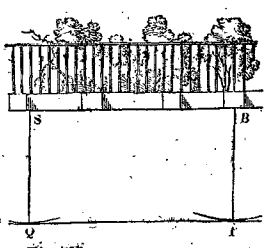


Fig. 797.

Perpendicular lines are those placed upon another in such a manner that the adjacent angles formed by their intersections are equal, and consequently each is a right angle. A straight line is perpendicular to a curve at a given point, when it is perpendicular to the tangent to the curve at that point, in which case it is sometimes called a *normal* to that curve.

A straight line is perpendicular to a plane when it is at right angles with every straight line in the plane passing through the point of intersection: a plane is perpendicular to a plane, when any straight line in the first, which is perpendicular to the common intersection of the two planes, is also perpendicular to the second plane.

To draw a perpendicular at the end of a line: place one foot of the compasses in the point A, and the other in the point C; then from C as a centre, and with the radius C A, describe the arc D A E; from the point F, where the circle cuts the right line A B, draw a line through the point C till it cuts D A E in G: a right line drawn from the point A to the point G will be perpendicular to the line A B. When the perpendicular is to be raised in the middle of a line, or let fall from I and K, equally distant from H, strike curves intersecting at N and O, and a line drawn through these points of intersection will be the right line or perpendicular required.

Should the point not be in the middle, as is the case at X, on the line YZ, the points 1 and 2 must be set out at equal distances from it, and then arcs of intersection struck.

Or if it should be required to drop a perpendicular to the line Q R, from a point situated at P, then from P as a centre strike the curve S T, and where it crosses the line Q R, with the same radius form the intersecting curves at V, and draw the line P V, which will be the perpendicular required.

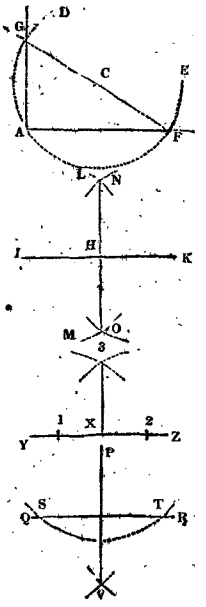


Fig. 798.

Scale is a term applied to a mathematical instrument, containing an assemblage of lines and figures, by means of which certain proportional quantities can be taken; in mensuration it signifies a line or rule of a definite length, divided into a given number of equal parts, and is used for measuring other linear magnitudes. An ordinary scale is usually set out by stepping the compasses along a given line, very lightly from one end to the other; the distance between the points being previously determined on. Sometimes it is required to find out the scale by dividing the given line into a certain number of parts, and considerable nicety is necessary accurately to perform this: practice alone can effect it.

To construct a scale, considerable care is requisite that all the portions or divisions may be set out equally: to form one of 80 feet for instance, it is only required to step the compasses so many times along the line; or after 10 feet have been set out at one end, to take its extent, and then set out the remaining 80 feet. But when it is required to make a scale of 140 feet upon a given line, as G H, then it is better from G as a centre, first to strike the arc H S, and from H as a centre the arc G O, and then drawing the lines G B and H E, at the same angle from the line G H; these may be subdivided into the same number of equal parts; then, by uniting the points K Y, L X, M V, N T, O S, P R, they will cross the line G H, and leave all the divisions equal.

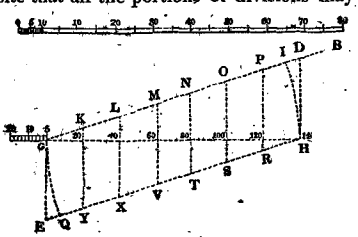


Fig. 799.

When it is required to divide a long line into a considerable number of equal parts, it is best, if the number will admit of it, to resolve it into two factors, and first to divide the line into the number of equal parts indicated by the small factor, then subdivide each of these parts into the number expressed by the larger; thus, in dividing a line into 150 equal parts, it is better to divide it first into fifties, and then into tens; it is advisable always, when the number of divisions is considerable, to adopt a small number at the commencement, and continue to subdivide them into the required portions, and when all is performed, to verify them over the whole length of line.

To construct two scales on two lines of unequal length, as suppose it is required to divide each of the lines M N and Q R into ten equal parts; take, or step along the line A K, ten parts, all equal, but of any length; then from the points A and K at the extremity of the line, strike arcs which intersect at L; from this point draw lines through C, D, E, F, G, H, and S; then from the point L, with M and N as radii, strike arcs which will cut at O and P, and with O and R as radii, other

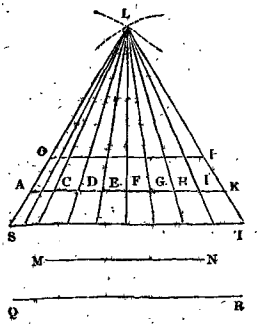


Fig. 800.

arcs cutting at S and T: then O P and S T will be the scales required; for as L A K is an equilateral triangle, the subdivisions on both lines, though of unequal length, must be equal.

Or, the straight line ab may first be divided into five equal parts, and afterwards subdivided from a and b; an equilateral triangle may be set out; then parallel lines, as cd, being drawn, scales of any length may be taken from it, all equally divided.

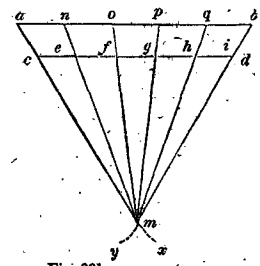


Fig. 801.

A scale divided into hundredths is very useful, particularly where the chain is made use of: ten equal distances are set out by as many horizontal lines, then from B to L, the equal distances, L, M, N, O, P, Q, are set out. Another division is set out, divided into tenths or hundredths at one end; on each horizontal is expressed a tenth by the sloping lines; on the horizontal line 2 2, may be measured two-tenths, on the line 3 3 that of three-tenths, and by descending, four, five, and six-tenths. Supposing, for instance, it is required to take off four chains thirty links, or three-tenths, placing the compasses on the fourth line horizontal

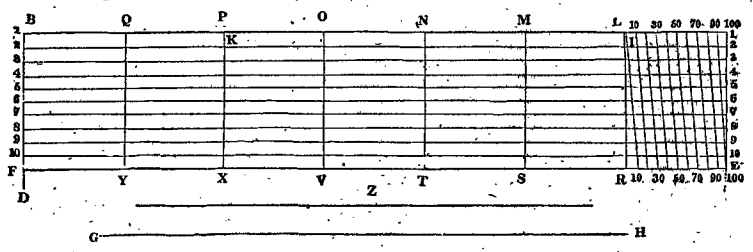


Fig. 802.

of P X, and extending them to the slant line numbered 30, you have the dimensions required, and so for any other within the limit of the scale, for it will be readily perceived

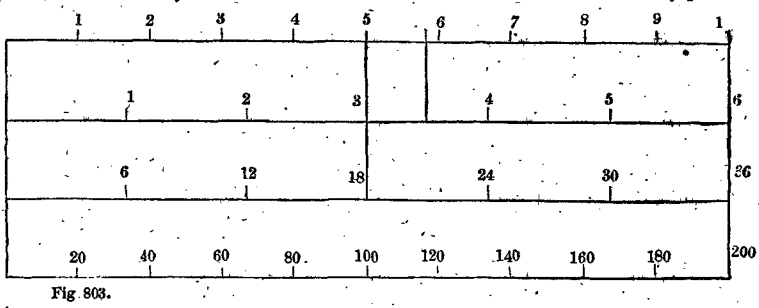


Fig. 803.

that the last division to the right contains the decimal arrangement. A B, C D, E F, G H, are scales of the same length, made to suit different measures, as those used in other

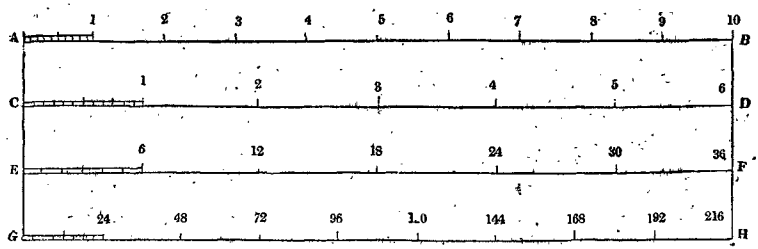


Fig. 804.

countries; or the first may be called a scale of tenths, the second feet, the third six times that scale, and the fourth six times that of the third.

Scales are often used as ratios, or for drawing lines which shall be in relative proportion

to each other; so that the first shall bear the same proportion to the second that it does to the third. A third proportional is required to the lines A B and C D, the first of which is double the length of the latter; draw any angle less than a right angle, as E, F, G. Carry the line A B from F to H on F G; carry C D on F E from F to I, and draw the line I H; then carry C D from H to K on the line towards G; make L K parallel to I H, then I L is the third proportional required.

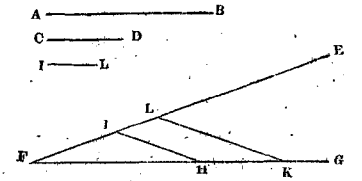


Fig. 805.

When a fourth proportional is required, an angle, as S F V, is set out at pleasure; from the point F, the line M N must be set out towards the point V, which will terminate at X. Carry the line O P on F S, where it will terminate at Y, draw the line Y X; then carry Q R towards V, and it will end at Z. Draw I Z parallel to Y X, and the length Y I will be the fourth proportional, as shown.

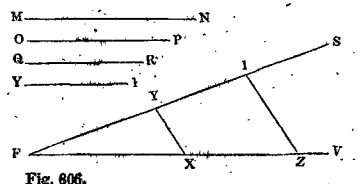


Fig. 806.

A mean proportional, found between the lines A B and K G, is found to be C D: for example, draw the line E P at pleasure, and set upon it the line A B and K G, which will be found to terminate at H; then divide E H into two equal parts by the point I; from this point as a centre, describe a semicircle. From the point G, which answers to the length of the line A B, raise a perpendicular, which will cut the semicircle at K; the line G K is the mean proportional to the line A B, C D: or the line A B is to K G, as K G is to C D. Should it be required to find a mean proportional to the lines L M and O Q, draw the line E P at pleasure, and carry on it the two lines L M, O Q. Describe a semicircle, and raise a perpendicular as before: then from E as a centre, as with the radius E K, describe an arc K R, which cuts the line E P in S; then the line E S is a mean proportional between the two given lines L M and O Q; that is to say, L M is to E S, as E S is to O Q.

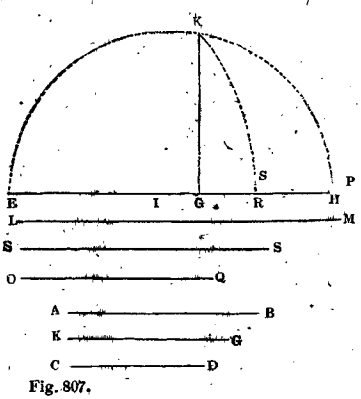


Fig. 807.

Arithmetical Proportion is when four magnitudes are proportionals; A, B, C, D may represent them numerically: then $\frac{A}{B} = \frac{C}{D}$.

Three straight lines are in harmonical progression, when the first is to the third, as the difference of the first and second to the difference of the second and third. Pythagoras is said first to have noticed in chords of the same thickness and tension the sounds of the fifth and its octave. These lengths are as 1, $\frac{2}{3}$, and $\frac{1}{2}$, the first of which is to the third, as the difference of the first and second is to the difference of the second and third.

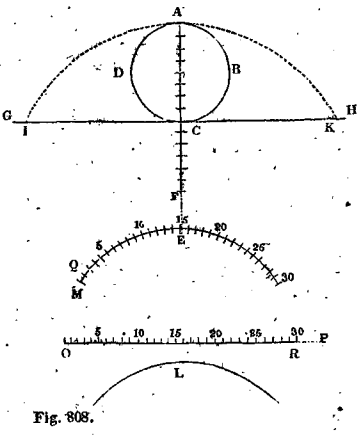


Fig. 808.

If a musical string is called C O, and its parts D O, E O, F O, G O, A O, B O, C O, be in proportion to one another as the numbers 1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$, their vibrations will exhibit the system of eight sounds, which are expressed by the notes C, D, E, F, G, A, B, C.

Harmonical Proportion, as it relates to architecture, is that where three numbers are in such relation, that the first is to the third, as the difference of the first and second, is to the difference of the second and third; thus 2, 3, and 6, are such numbers, because 2 : 6 :: 1 : 3; and four numbers are said to be in harmonical proportion when the first is

to the fourth, as the difference of the first and second, is to the difference of the third and fourth; 9, 12, 16, 24, are such; for 9 : 24 :: 3 : 8.

To trace on the ground a straight line equal in length to a circle, it is only necessary to divide the diameter A C of the circle into eight equal parts, and prolonging the line to F, upon which six of the divisions are to be set out.

Through the point C, at right angles, draw G H, and from F as a centre, with the radius F A, describe I A K, when A K will be the length sought.

When it is required to draw a straight line equal to a portion of the curve, as that of L, it may be done by dividing it into small portions as shown, set out from M, and transferring them to a straight line, as O P: by this means, it may be performed with sufficient accuracy for ordinary purposes.

To draw either on the ground or on paper angles of any kind, a protractor is sometimes made use of: this is a semicircular limb of metal, divided into 180°, and subtended by a diameter, in the middle of which is a line and dot to mark the centre of the circle, to which all the divisions of the degrees radiate.

By this simple instrument an angle of any number of degrees may be set out by laying its straight edge on a line previously ruled upon a sheet of paper, and then marking off the angle required; lines then drawn from the dot or centre will fully express it.

When this instrument is made use of for surveying on a large scale, it is formed into an entire circle, with four arms radiating from the centre. A circular disk of glass is placed over a hole in the centre, on which two lines are drawn, crossing each other at right angles: round this is a small circular ring of brass, which carries two arms, one of which has attached to it a vernier, which moves over the outer circle, divided into degrees, and the other a head, which can be moved round, and made to turn a small pinion that works in a toothed rack round the outer edge of the protractor. The arms are moved by this rack and pinion entirely round the whole circumference, and the vernier can be set to any particular angle. The arms are made to extend over the outer rim, and each carries a fine point, which is pressed down when the instrument is to be used, and these make a small dot or hole in the paper.

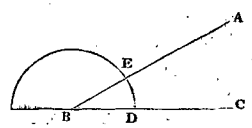


Fig. 809.

To draw an angle of 30° on the line B C, for instance at the point B, the demicircle has its dot or centre laid at B; the number of degrees are counted off from D to E, and then, moving the protractor, a line is drawn from B through E, and A B C is the angle required.

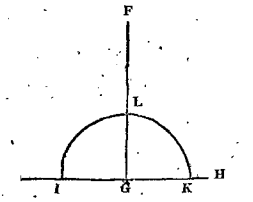


Fig. 810.

Or from the point G, on the right line I H, it is required to set out an angle of 90°. Place the centre of the protractor at the point G, and its diameter I K along the line I H; then counting off the number of degrees, and mark the point, as at L, remove the instrument, and draw the line G F through L, and H G F will be the angle required.

The same may be done by placing the protractor at N, and its diameter along the line O P, and counting from this line O P on the circumference of the protractor 144°, as from R to S, draw then the right line N M through S, and the obtuse angle of 144° is obtained.

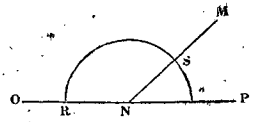


Fig. 811.

As this is a right angle it is only necessary to raise a line perpendicular to another to obtain it: the side of a square makes an angle of 90°, and its diagonal one of 45°, or the half.

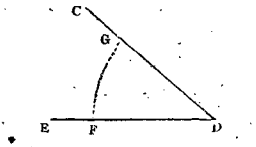


Fig. 812.

The division of an angle into any number of equal parts is termed its angular section; and its *trisection* requires the aid of solid geometry, being equivalent to the solution of a cubic equation; the general division of an angle into any proposed number of equal parts, is a problem which mathematicians have not yet solved.

To draw on a right line an angle equal to any given angle, as on the line A B, from the point A, to draw an angle equal to the given angle C D E. Place one foot of the compasses on the point D, and strike the arc F G: with the same radius, from the point A, strike a similar arc from H to F; then take the height from F to G, and transfer it from H to K: draw the line A L through K, and you have what is required.

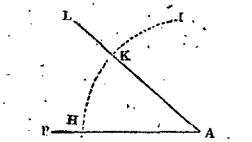


Fig. 813.

When angles are to be set out upon the ground, lines or cords are made use of; and if an angle of 144 degrees is to be set out from the line O P, the centre of the protractor must be placed at the point N, or where the angle is required, and then the number of degrees counted from R to S, and then a string or cord attached to the point N is stretched over the division at S towards M, and O M is the angle required. Or, what would be the same thing, the smaller angle of 36° may be counted off from the base line towards S.

By the same means, on the line M N, from the point O, an angle equal to C D E may be drawn, and so of other angles; but sometimes it may be required to make on the cord S T, at its extremity S, an angle equal to P R Q; we must then fix a stump or piquet at the point R, and another at each of the points P and Q, V and X. Then, with a cord, we must measure the distance from R to X, and set it off from S towards Y, and place a piquet there; from X we must take the distance to V, and set it off from Y to Z, describing an arc at Z. Then the length R Y is set off from the piquet S, and an arc described cutting the other at Z: through this point of intersection a line is to be stretched, and then the angle Z S Y will equal that of V R X.

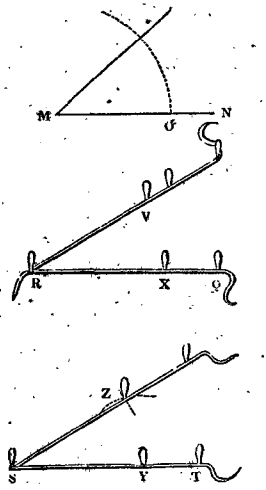


Fig. 814.

An Equilateral Triangle upon the base line A B is formed by striking arcs of a circle, having the same radius from the points A and B: where these intersect at E, B C and A D are drawn, and the figure is complete.

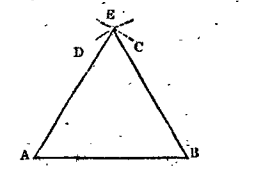


Fig. 815.

Before any of these figures can be set out, it is necessary that a straight line should be first established, and the engineer commences by marking the two ends of the required line, by fixing at each point a piquet staff. Then taking up a position at a short distance behind one of them, and closing one eye, he looks along the edge of one staff, and directs his attendant to place between the two piquets first set up other intermediate ones at regular distances, taking care that they are all so placed that they are in the line between the two first. This kind of adjustment, which is termed boning a line through, requires considerable practice before it can be relied upon; and the assistant who follows the direction of the engineer must well understand the signals that are made to him by the motion of the hand to the right or the left, or the difficulty will be increased. The same practice is adopted in setting out a base or any other straight line when an instrument is used; and all lines which are to be measured should be previously set out in this manner, for then those who carry the chain will be guided in the right direction, and not be subject to a deviation, which, whether to the right or left, would increase the dimensions beyond the truth. All diagonals and angles require the same precautions to be taken, where accuracy is desired. After a base line is established, perpendiculars and angles may be raised upon any point of it in the manner already described.

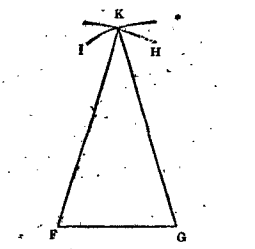


Fig. 816.

In an *Isosceles Triangle* the angles at the base are equal to one another, and if the equal sides are produced, the angles upon the other side of the base are likewise equal: to set out such an angle from the point F, with any radius greater than the base F G, describe the arc H, and from the point G describe with the same radius the arc I, cutting each other at K: draw F K and G K: K G F is the isosceles required. The isosceles triangle, which has the two equal sides less than the base, may be set out in a similar manner, using, however, from the points M and N a radius less than its length, which will intersect each other at L: L M N will then be the isosceles required.

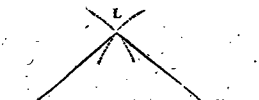


Fig. 817.

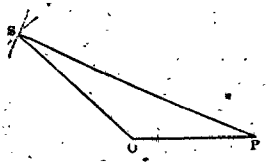


Fig. 818.

A Scalene Triangle may be formed on the line O P of any required dimension; from the point O strike the arc which will intersect another struck with a different radius from P: and then by drawing through S the lines O S, P S, the angle is formed.

Triangles, similar and equal to others, may be set out on straight lines by taking the length of the base of the given triangle, C E D, and carrying the length D E on the line A B from A to F. Then from the points A and F, and with the radius A F, describe the arcs which shall cut each other at G: draw the lines G A, G F, when one will be like the other.

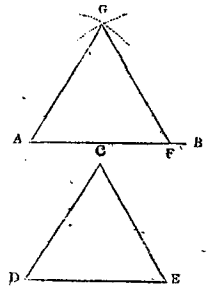


Fig. 819.

If two triangles have two sides of the one equal to two sides of the other, each to each, and likewise the included angles equal; their other angles shall be equal each to each, viz. those to which the equal sides are opposite, and the base or third side of the one shall be equal to the base or third side of the other. And if two triangles have *two angles of the one* equal to two angles of the other, each to each, and likewise the sides lying between equal; their other sides shall be equal each to each; viz. those to which the equal angles are opposite, and the third angle of the one shall be equal to the third angle of the other.

An isosceles triangle may be similarly imitated: take the length of the base L M, and mark it out from H to N; then from the points H and N, with the radius L K or M K, describe the arcs at O; where they intersect at P, the lines H P and N P are to be drawn. The two isosceles triangles will then be similar.

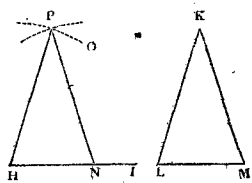


Fig. 820.

In an isosceles triangle, if a straight line be dropped or drawn from the vertex to any point in the base, or in the base produced; the square of this straight line shall be less or greater than the square of either of the two sides, by the rectangle under the segments of the base, or of the base produced.

The scalene triangle X Y Z may be set out at S T Q in a similar way; and either of these operations may be performed on the ground by means of cords and piquets.

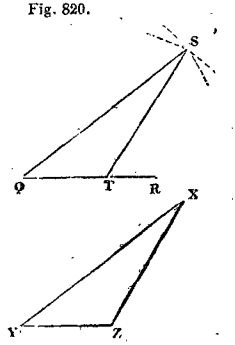


Fig. 821.

Whatever the form of the triangle, the square of the side which is opposite to any given angle is greater or less than the squares of the sides containing that angle, by twice the rectangle contained by either of those sides, and that part of it which is intercepted between the perpendicular let fall upon it from the opposite angle and the given angle; greater when the given angle is greater than a right angle, and less when it is less.

In every triangle the squares of the two sides are together double of the squares of half the base, and of the straight line which is drawn from the vertex to the bisection of the base: every triangle is a mean proportional between two rectangles, the sides of which are equal to the semi-perimeter of the triangle and the excesses of the semi-perimeter above the three sides.

To draw a triangle similar to another, either with or without a scale, as that shown at A B C, the side A B measuring 90 feet, the side A C 70, and B C 42, make a scale of any convenient length, divided into feet, and then draw a similar triangle, using for radius the dimensions taken from the scale; by this means the figure may be enlarged or reduced according to pleasure, or to the dimensions determined by the divisions of the scale. In the present example, 70 feet radius taken from the scale is made to cut that of 42: the two centres, being F and H, also set out at 90 feet distance on the base line G from the same scale.

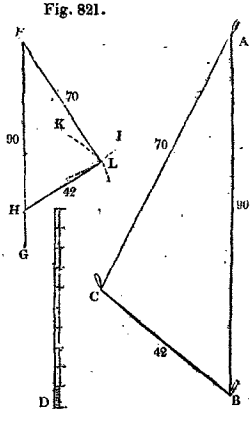


Fig. 822.

It must appear evident, if we make the three angles of the one triangle equal to those of the other, whatever may be the difference of the size, their shape will be similar; we may in one instance use a scale where each minute of a degree is an inch, and in the other a foot; still if we employ the same scale to each by which it was set out, the area or content will be the same.

In doubling or quadrupling the contents of a figure, it is only necessary to prepare cor-

rectly the scales by which they may be set out; irregular forms may always be cut up into squares or triangles, and master lines may be drawn generally from the extreme points upon which the outlines may be constructed.

The triangle T R S may be enlarged to Y P G in a similar manner, or without a scale, by taking care to make their angles correspond.

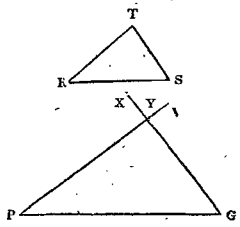


Fig. 823.

A Square may be constructed on the line A B, by setting out first the length of its side from A to C, and then using these points for radii, striking two arcs which will cross each other at F. Then divide the line F A in P; set off the distance F P towards H and G on the arcs struck from A and C; then draw A G, C H, and G H, and the four sides will be equal.

A square may easily be set out by means of the protractor, whose diameter being laid on the line I K, the perpendicular L I can be marked out: then from I as a centre, and L as a centre, strike the arcs N O, M O; unite K O, L O, and the square is formed.

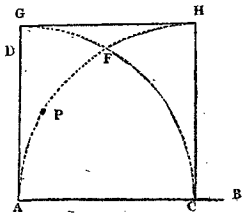


Fig. 824.

Every rectilineal figure may be divided into triangles, and every triangle being equal to half the rectangle under its base and altitude, contains half as many *square units* as is denoted by the products of the numbers which express how often the corresponding unit is contained in its base and altitude. Suppose the linear unit to be a foot, and it is required to find how many square feet there are in a triangle whose altitude and base are 10 feet, the rectangle of the sides of which is 100 feet; therefore the triangle contains half that area, or 50 feet. It is on this account we say that a rectangle is equal to the product of its base and altitude; a triangle to half the product of its base and altitude.

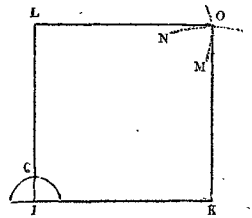


Fig. 825.

The length of a line or a side is the linear units it contains: the area or superficies is the number of square units on its surface. A square whose side is 22 yards long is the tenth part of an acre, therefore $22 \times 22 \times 10 = 4840$ square yards, which is the magnitude of the statute acre. The chain employed to measure land is of this length, so that 10 square chains make an acre. In Ireland 121 Irish acres are equal to 196 English, and 48 Scotch are equal to 61 English, and in France 40·466 acres are equivalent to 1000 English acres.

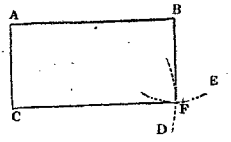


Fig. 826.

In setting out any given area the simplest method is to resolve the whole either into squares or triangles; in the figure the radius represented is 22 yards: it is evident we should have an area of the tenth of an acre within the square A G H C, and the square root of 4840 would give us the length of the side that would contain the acre, which is 10 chains or 220 yards.

The Parallelogram A B C F may be also set out in a similar manner, using for radius the length of their respective sides, and through the points of intersection drawing the lines which are to bound the figure.

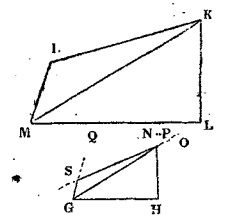


Fig. 827.

Trapezoids may be made either larger or smaller than others, as well as similar, by dividing them first into triangles by the diagonals M K and G P, and then taking care that the angles are made equal. At the point G, on the side G P, the angle P G Q is made equal to the angle K M I, and at the point P the angle G P R is made equal to M K I. Then the triangle S P G is similar to I K M, and the trapezoid S P H G is similar to that of I K M L. To draw a triangle that shall be equal to a given circle, it is only necessary to draw a line equal to the circumference, and at one end to erect a perpendicular equal to radius, and then to unite this right angle by drawing an hypotenuse.

The area of a circle being equal to half the product of the radius and the circumference, and the area of the triangle being equal to half the product of its height and base, the surface or area of a triangle so constructed and that of the circle must be equal.

METHOD OF DRAWING MULTILATERAL FIGURES.—*The Pentagon* A is drawn by describing a circle from the point B of the given size: then from the centre B draw the two diameters C D and E F at right angles, and from the point G, which is half the radius of E B, describe the arc C H; the length C H will be the side of the pentagon, which may be traced round the circle.

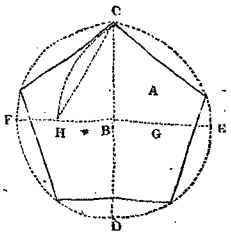


Fig. 828.

To inscribe a regular pentagon within a circle, divide the radius B F medially in the point H, so that B H may be the greater segment: draw the radius B C, at right angles to B F, and join C H: then because the square of C H is greater than the square B H by the square of the radius C B, and that B H is the side of the inscribed decagon, C H is the side of the inscribed pentagon. Therefore a chord equal to C H will subtend a fifth part of the circumference, and if the circumference be divided into five parts with chords, each equal to C H, a regular pentagon will be inscribed. To inscribe a regular decagon, divide the radius medially, and divide the circumference into ten parts with chords each equal to the greater segment of the radius so divided.

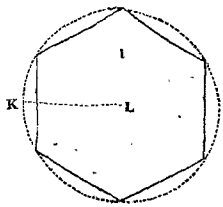


Fig. 829.

The Hexagon has its sides equal to its radius, and is made up by six equilateral triangles; the diameter of the circle which contains it, when cut by a perpendicular passing through the centre, forms right angles with the two sides it touches.

The Heptagon M. On a circle of any given diameter fix the point N: with the radius N O describe the arc P O Q, and draw the chord line P Q; the half of this chord will be the side of the figure required.

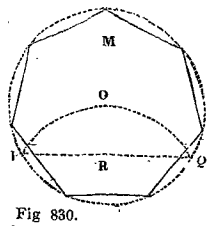


Fig 830.

It must be admitted that we have no exact rule for setting out this figure, and we can only inscribe it within a circle approximatively. This is sometimes done by continuing the series 4, 8, 16, &c., which represents the number of parts into which the circumference may be divided by continued bisections, until a number be found which is greater or less by 1 than a multiple of 7. 64 is such a number, being greater by 1 than 9×7. Now, if the circumference be divided into 64 parts, and an arc be taken equal to 9 of those parts, which is less than a seventh part of the circumference by a seventh part, the error may be made up by a little calculation, and the side obtained near enough for most practical purposes.

The Octagon S. Describe a circle, and draw the two diameters V X and Y Z at right angles through its centre; then divide one quarter of its circumference into two equal parts, and so on with the rest.

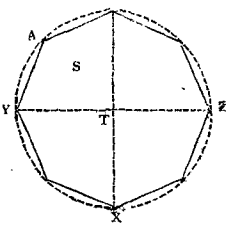


Fig. 831.

The octagon may also be set out by two squares, so placed that their diagonals are at right angles with each other, and also by bisecting the arcs which are subtended by the sides of a square.

The Nonagon B. Describe a circle, and carry two-thirds of its radius nine times round it.

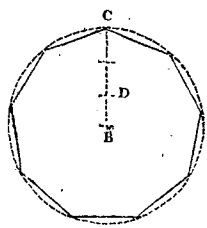


Fig. 832.

The same method may be adopted for this figure as described for the heptagon: seven times the arc, which is assumed as the seventh of the circumference, falls short but little of the whole circumference; and 9 times the arc by about the same, therefore both are near enough for all practical purposes.

Any polygon may be decomposed into triangles, by drawing straight lines from one of its angular points to each of its opposite angles, and the area of the polygon is the sum of the areas of all the component triangles: their area may be found without this process, which, when the number of sides is considerable, leads to some labour; the theorem was established by L'Huilier, who found that the double of the surface of any rectilinear figure is equal to the sum of the rectangles of its sides, taken two and two, *excepting one*, multiplied by the sine of the sum of the supplements of the interior angles contained between each pair of sides.

To investigate the general property of polygons, we must divide them into two classes, convex and concave, the first being those in which all the interior angles are less than two right angles, and the second those which have one or more re-entering angles. If we term those the interior angles of the polygon which belong to the interior of the figure, whether less or greater than two right angles, and those exterior angles which are obtained by subtracting each interior angle from four right angles, we shall have the two classes.

The Decagon. Describe a circle, and divide the radius into two equal parts, as at M: from this point, with the radius M H, mark the point N; the distance G N will be the side of the decagon.

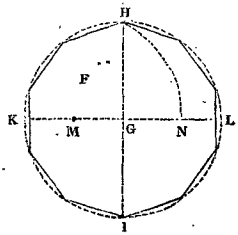


Fig. 833.

By a reference to the pentagon we have also the means to set out this figure, the operation being nearly the same.

The Undecagon. Draw a circle, and cut it in the centre, P, by two lines, Q R and S T, drawn at right angles from the point R; with the radius R P, mark on the circumference the point V, and draw the right line V Q; it will cut the radius P S in X; the length P X will be one side of the undecagon.

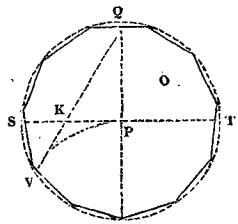


Fig. 834.

The area of the circle was computed by means of inscribed and circumscribed polygons; and of all plane figures having equal perimeters, the circle contains the greatest area; and consequently, of all plane figures containing equal areas, it has the least perimeter. The circle, therefore, is a maximum of area and a minimum of perimeter.

The Dodecagon is formed by carrying the length of one half the radius round the circle.

Another method may be described for the setting out of these figures.

On the line A B set out two equal parts, and at their division, or the point D, elevate the perpendicular line C D; then from the point A, with the radius A B, describe the arc B E, which will cut the perpendicular C D in the point F.

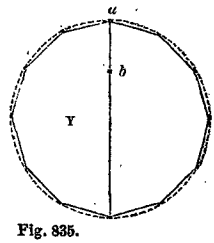


Fig. 835.

Then describe from the point F, with the radius F A or F B, a circle: the length A B carried six times round forms the hexagon. By dividing B F into six equal parts in the points L, M, N, O, P, and F, and from the point F taking the radius F P, and describing the arc P Q, which cuts the perpendicular C D in R: from this point R as a centre, with the radius R A, describe a circle, and carry the length A B seven times round it, and it will form a heptagon.

To form an octagon take the second division F O and work before, and so on with all the other figures. Thus the whole of the regular polygons may be drawn by increasing the diameters of the circles by one division each time, which will give several points on the perpendicular C D, whence circles may be described on which may be carried the line A B as many times as may be necessary to construct the required polygon.

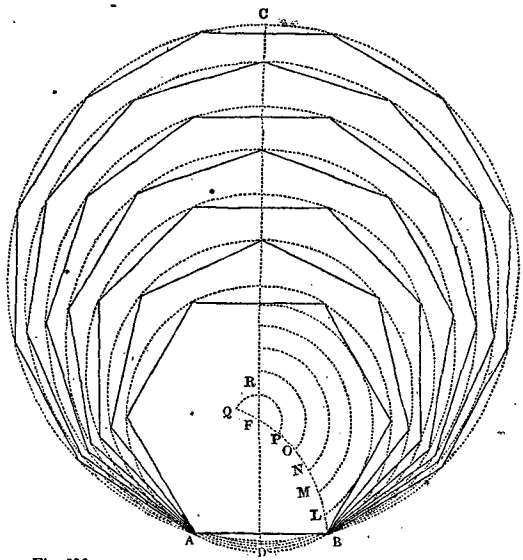


Fig. 836.

METHOD OF DRAWING POLYGONS ON RIGHT LINES BY MEANS OF DEGREES. — *For the Pentagon* divide 360 degrees by 5, and the quotient gives 72 degrees for the angle in the centre of the pentagon; then subtract these 72 degrees from 180, the value of the three angles of a triangle, there remains 108 degrees for the angle of the figure, the half of which, 54, will be the angle of the demi-polygon. Then make at the point A on the given line A B the angle B A C of 54 degrees by placing the centre of a protractor on the point A, and making its diameter coincide with A B: count 54 degrees on the circumference, which will terminate at D, and having removed the protractor, draw from the point A through the point D a line A D C, which will form an angle B A C of 54 degrees. The same process must be repeated at the point B, the other extremity of the given line A B, in order to draw the line B E, which will cut A C in F and form a centre, from which, with the radius F A, a circumference may be described, on which, if we apply the line A B five times, we shall form the pentagon A G H I B, and by a similar method all the other polygons.

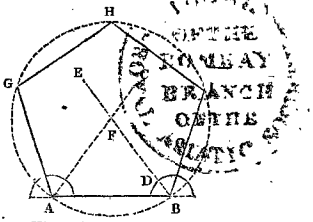


Fig. 837.

METHOD OF DESCRIBING CIRCLES, OVALS, PARABOLAS, SPIRAL LINES, ETC. — The following table of factors is sometimes made use of to construct a circle geometrically: suppose c to be the circumference of a circle, the diameter of which is unity, and x the side of a square equal in area to it, and let a be the area of the circle: then $c = 3{\cdot}14159$; $2c = 6{\cdot}28319$; $\frac{c}{2} = 1{\cdot}57080$;

$\frac{c}{12} = 0{\cdot}26180$; $\frac{c}{360} = 0{\cdot}00873$; $\frac{1}{c} = 0{\cdot}31831$; $\frac{2}{c} = 0{\cdot}63662$;

$\frac{360}{c} = 114{\cdot}59156$; $x = 0{\cdot}88623$; and $a = 0{\cdot}78540$.

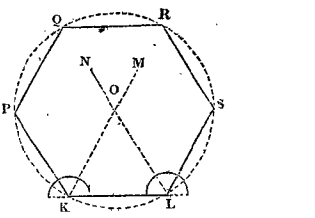


Fig 838.

To describe a Circle.—Place one foot of the compasses in the place where the centre is to be, and with the radius required describe the circle: to set out a circle on the ground, fix a piquet or staff in the place where the centre is to be, as at A, and tie the end of a cord to the piquet by a slip knot, so as to turn round easily. Then to the other end of this cord attach a staff, B, at the distance required for the radius, and then describe the circle by stretching the cord A B equally, and being careful to keep the staff B perfectly perpendicular, and not to allow the cord to touch the ground.

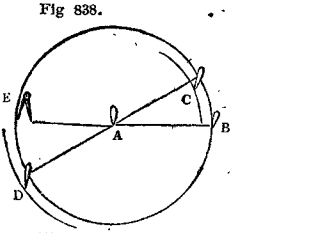


Fig. 839.

To divide a Circle.—Divide the diameter A B into as many parts as it is required; then from the point A, with the length of the diameter, describe B C, and from the point B, with the same radius, describe A C. From their point of intersection, through the division marked 2, draw the right line C D until it touches the circle: the line A D will be one-fifth of the circumference, the diameter having been previously divided into five equal parts. By this means any circumference may be divided, so as to inscribe any regular polygon, remembering that we must always draw the line C D through the second point of the division of the diameter A B, whatever the diameter of the circle may be divided into: to form an equilateral triangle it must be drawn through both points of division.

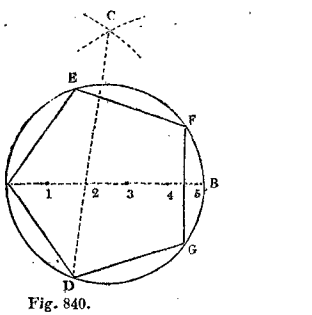


Fig. 840.

To draw a Circle through three given Points.—It is necessary that the three given points should not be in the same line. Let it be required to draw a circle through A, B, and C. If on the ground, take the distance between A B with a cord, or if on paper with the compasses, and describe above and below, from the points A C, the arcs D E and H I, and with the same radius from the point B intersect them: then draw lines through their points of intersection, and where they cross will be the centre, from which a circle may be described, that will pass through the three given points.

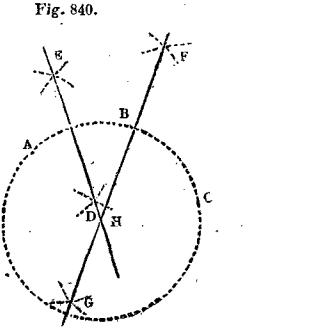


Fig 841.

This method of describing circumferences of circles is of

service to architects and others, enabling them to discover the entire form, when any portion of the figure has been destroyed.

To find the centre of a circle or any portion of it, take any three points in the circumference of the circle, as A, B, and C: then from the points A, B, with the radius A B, describe four arcs intersecting at E and D, through which points of intersection draw at pleasure the right line E D; then from the points B and C with the radius B C, describe four other arcs intersecting at F and G, and through these points draw the line F G cutting E D in H, which will be the centre of the circle A B C.

To find the centre of a portion of a circle, as that of I K L, draw the right line I L, and divide it into two equal parts in the point M; then raise a perpendicular from the point M, and prolong it towards the base until it cuts the portion of the circle I K L in K; then measure the distance I M, which here is found to be $6\frac{2}{3}$ parts, and the distance M K 4 parts; then multiply $6\frac{2}{3}$ by itself; the product $44\frac{4}{9}$ must then be divided by 4, and the quotient $11\frac{1}{9}$ must be counted as the line M N from M to C; then divide the length K O into two equal parts in the point P, which will be the centre of the circle. The centres of basins or reservoirs of water may be thus found, even when portions of them have been destroyed.

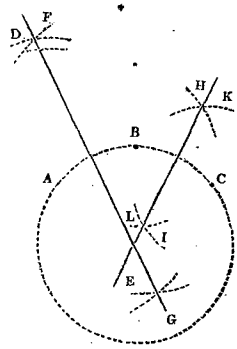


Fig. 842.

Method of describing Ellipses.—To draw the oval A, trace a right line C D of the length required for the oval, and divide this line into four equal parts by the points E, F, G; from the points E, F, and G, with one of these divisions as radius, describe three equal circles: on the point F, the centre of the line C D, let fall the perpendicular H I, which will cut the circumference of the circle F G in K and L; from the point K through the centre E, draw the right line K E, until it cuts the circle C F in M, and in like manner from the point I, through the centre G, draw the right line L G until it cuts the circle F D in M; then from the point K, with the radius K M, draw the line M O, and from the point L the line P N. The curved line C P N D O M is the oval.

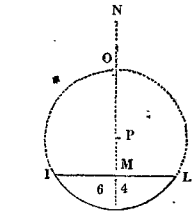


Fig. 843.

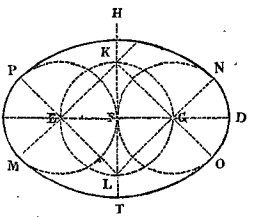


Fig. 844.

When it is required to draw a more rounded figure, as B, whose diameter is the same as C D, it is only necessary to divide the line C D into three equal parts in Q R, and from the two points Q, R, with the radius of one part, as Q C, describe the circles C R and Q D; then at their points of intersection, S, T, draw the perpendicular S T across C D; then take two equal parts out of the three, and with the compasses, from the point S describe the arc V X, and from the point T the arc Y Z: the line C Y Z D X V is the oval required.

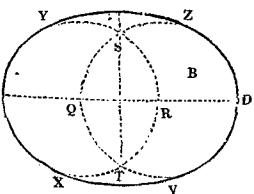


Fig. 845.

To draw an Oval when the two diameters are given, as C D for the longer, and E F for the smaller, take half the smaller diameter, as G E, and set it off on the greater diameter C D from G to H, and from G to I: divide G H into three equal parts, and carry two parts on to the smaller diameter E F from G to K, and from G to L. From the two points K and L, draw four right lines of any length through the points H and I: from the point H as a centre, with the radius H C, describe the arc N C M, and from the point I, with the same radius, describe the arc O D P; then from the point L, with the radius L M, describe the arc M E O, and from the point K, with the radius K N, describe the circle N F P; the line C M E O D P F N will form the oval A on the two given diameters.

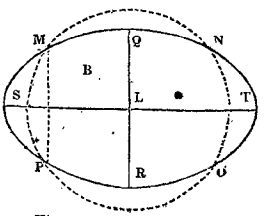


Fig. 846.

To draw an oval similar to B, the two diameters of which, Q R and S T, cross at right angles in the point V, take with a thread or cord the length of the greatest diameter Q R, and double the thread; place its two ex-

tremities X and Y on the greatest diameter Q R, equally distant from the centre V, so that the fold or angle of the thread exactly reaches the point S and the point T; then place a pencil-point at the end of the doubled thread, and move it round until the extremities Q R and S T have been passed through, which will form the oval required.

To find the Centres of an Oval. — Draw in any part of the oval the right line C D, and at any distance its parallel E F; divide these two parallel lines into two parts in G and H, and trace through these points the lines I G H K; then bisect this right line in the point L, which will be the centre required.

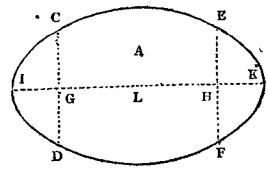


Fig. 847.

To find the two Diameters of an Oval when the centre is known, it is required to find the lengths of the longer and shorter diameters of an oval whose centre is at L. Describe from the centre L a circle which shall exceed the oval both above and below, and note where the circle cuts the oval, as in the points M N O P, in order to draw through those points M and P the right line M P, to which a parallel line must be drawn, passing through the centre L, to the circumference of the oval, as Q R, which will be the lesser diameter of the oval; then cut the lesser diameter Q R at right angles in the centre L by the right line S T, which will be the greater diameter of the oval.

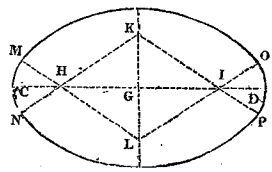


Fig. 848.

Method of drawing Parabolas, &c. — Trace the right line A B, of the length required for its base, and divide it into two equal parts in the point C; from this point raise a perpendicular C D, of the length required for the axis of the parabola; divide this axis into several equal parts in the points E, F, G, H, I, and D: through these points of the axis C D, draw transverse lines parallel with the base A B; prolong the axis C D to infinity, as to K. Divide the first space I D into two equal parts, as at L; take the length D I, and set it off from D towards M; then take the distance M I, and set it off from L to the extremities of the first transverse line, at the points N and O; then take the length M H, and set it off on the second transverse line, as at P and A: take also the distance M G, and set it off from L, to the extremities of the transverse line C, as at the points R and S, and do the same with all the other lines: then through these extremities so marked off, trace the line A X T, &c., which will give the parabola.

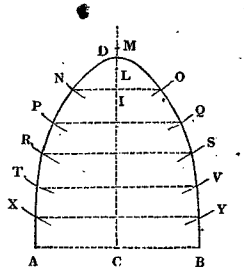
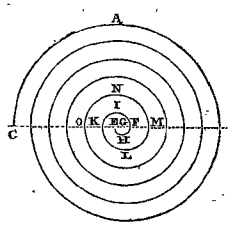


Fig. 849.

Method of describing Spiral Lines, which are either simple or compound; the first are those which are formed by a single line, and the latter those which have a double one. A simple spiral is drawn by tracing the line C D, and making upon it the position of the eye of the spiral G; then from this point G, with the radius G E, describe the semicircle E H F; and from the point E as a centre, with the radius E F, describe the semicircle F I K; then from the point G, taken again as a centre, with the radius G K, describe the semicircle K L M; then from E as a centre, with a radius E M, describe the semicircle M N O. The same process must be repeated alternately from the centres G and E; and thus semicircles must be traced at the interval where the preceding circle ceased, until the spiral is of the size required.



To draw a compound spiral, a simple one must be first drawn; then set off from the point E to P, the extent to be given to the width of the band, as E P; then from the point G, with the radius G P, describe the semicircle P Q R, and from the point E as a centre, with the radius E R, describe the semicircle R S T: in like manner also, from the point G as a centre, with the radius G T, describe that of T V X, which must be continued alternately from the centres E and G, until the several spirals answer to the former.

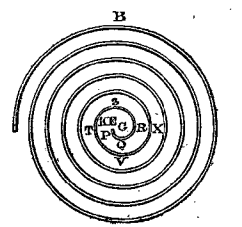


Fig. 850.

The Construction of Solids comes more under the denomination of descriptive geometry, and on the Continent it has for many years formed a branch of study for engineers, both civil and military: it cannot be too highly esteemed, as it consists in the application of all the known rules of projection, to exhibit on a plane the figures of the solids, as well as to show their method of construction. The plane surfaces of all solids are bounded by edges, which can be expressed by straight lines: and in the construction of a solid we have to regard three varieties of angle: the first are those where the lines meet which bound the figure; the second, those which result from several faces meeting to form a solid angle; and thirdly, those which are formed by two planes or faces.

We shall find that cubes contain six equal planes, twelve edges, and eight solid angles, and that in all solids with plane surfaces, the edges terminate in solid angles formed by them, or where they unite with each other: and to find the projections of the right lines which represent those edges, it is necessary that we should know the position of the solid angles where they meet, and these are formed generally of several plane angles.

To make a Triangular Pyramid, draw the triangle D E F of the required dimensions, and then fix the point G where the summit is required, and unite lines from each of the points D E F of the base in this point, which will give the figure required. All other pyramids, as those with square or polygonal bases, are set out in the same manner.

Pyramids may be regarded as solids standing on polygonal bases, their planes or faces being triangular, and meeting in a point at the top, where they form a solid angle.

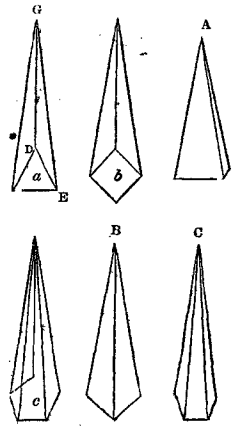
To construct a Pyramid or a Tetraedron in relief, in card, or other material, the base must be set out as at I; then at the sides the other triangles must be formed. These three outer triangles are then raised and united at the top, which will form the tetraedron required. If the faces which meet at the apex are required to be longer than the equilateral triangle, after the base is set out, the isosceles triangle must be traced of the height required, and when cut out, united at the point or summit as before.

It will easily be seen that a tetraedron may be inscribed in a tetraedron, an octaedron in a cube, and a cube in an octaedron, an icosaedron in a dodecaedron, and a dodecaedron in an icosaedron.

The mutual relation between the regular solids is very curious: when lines are drawn from the centre of the circumscribed solid to its different angular points, these lines will be perpendicular respectively to the faces of the inscribed solid; so that if we cleave or cut away the solid angles of the circumscribed figure by planes perpendicular to these lines, and if we continue the process until we arrive at the centres of the several faces, we shall obtain the regular solid, which is inscribed, and which forms, as it were, the nucleus of the other. By cutting away the solid angles of the tetraedron, we also form the octaedron.

To find the inclination of the two adjoining planes of a tetraedron, we have only to consider that the required inclination is that of two angles of equilateral triangles, which, together with a third, form a solid angle, and therefore may be easily constructed: in a cube the angle of inclination will be a right angle.

To draw or construct Prisms. — Set out its base of the number of sides given; then from the angles of the base D C H, &c., elevate perpendiculars of the height to be given to the prism, in such a manner that we join the points I, C, N, &c. Hollow prisms may also be set out, by giving the thickness and drawing as it were one prism within the other.



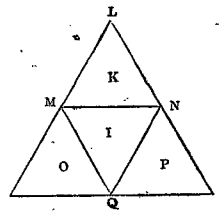


Fig. 851.

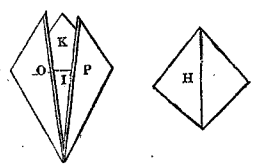


Fig. 852.

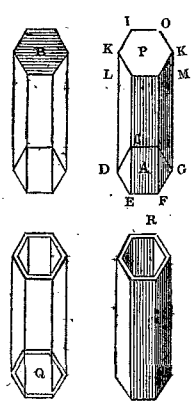


Fig. 853.

To construct a Prism. — Form on each side of the base T its sides X Y, of the length required, and also the top V of the size and form of the base, and then the whole may be folded together to form the prism or figure required. In the figure shown at S, we have a simple right prism, the faces being all perpendicular to the ends; the developments are consequently all rectangles which are joined together at the edges and enclosed at each end.

V shows the plan of an hexagonal prism, and its manner of uniting the sides Z to form a regular figure.

To draw an inclined prism, we commence by tracing the profile parallel to its degree of inclination, and then describing on its axis the plane which is perpendicular to it; afterwards by lengthening the lines which represent the edges, we may project the horizontal section, as is shown in the development of right and oblique cylinders.

The Tetraedron. — The three triangles which surround that in the middle, and which are made to meet in a point at the summit, form a figure with four faces. To form this out of paper or card, it is only necessary to partly cut through the lines to enable it to fold.

A sphere may be circumscribed about a given tetraedron, as well as inscribed within it.

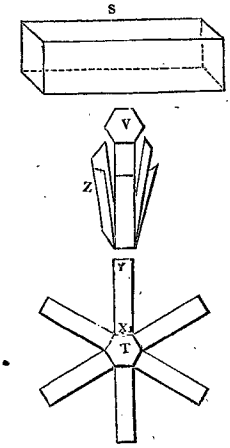


Fig. 854.

The sphere or globe may be considered the chief or primary figure, and the standard of proportion to the triangular prism, the cylinder, and the cone: the discovery of the diagram of a sphere inclosed within a cylinder on a tomb at Syracuse led Cicero to pronounce it as that of Archimedes. In the triangle we might inscribe a circle, which would represent the base of the three secondary figures, and among the Saxon-sculptured ornaments we find the globe encompassed by an equilateral triangle, which is readily effected by sinking the stone without the circle, and then rounding off its edges to produce the hemisphere. Taquet, in his Theorems of Archimedes, has added "Una tribus ratio est" to the diagrams in which is represented the prism, the cylinder, and globe. Length, breadth, and depth constitute a geometrical solid, and these three dimensions belong to the parallelopipedon, the tetraedron, and the sphere: the first of these figures is said to be cubic, plinthic, and oblong; the second, equiangular, obtuse, or acute; and the third, right, oblate, and ovate; of these varieties there are many subdivisions. The sphere is the most perfect of the whole, as it comprehends all others in its centre, diameter, radii, and circumference.

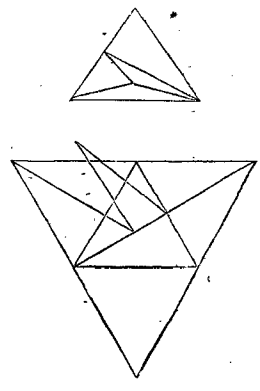


Fig. 855.

To draw a Hexaedron or Cube, or to construct one, an exact square must be set out for a base; then on the sides the four squares R S T P, each equal to O, and attached to P another square Q, which, when folded together, forms the top. Care must be taken to make allowances for the joining or uniting at the angles.

Cubes are variously represented: the top D may be shown of the same dimensions as the front C, or the double cube may be drawn with its top, I K L M, double the face or front G H I K; it may be shaded, as N, and the dotted lines E F omitted.

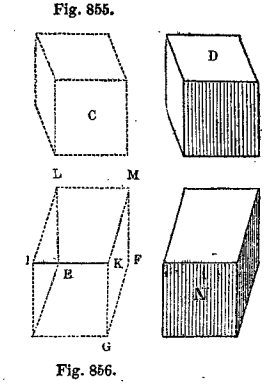


Fig. 856.

Mr. Peter Nicholson, in his Practical Treatise on Stone-cutting, says, "Every stone bounded by six quadrilateral planes or faces forms a solid, of which the surfaces terminate on eight points, every three surfaces in one point: every three planes thus terminating is termed a solid angle or *trihedral*. The angles formed by the intersections of the faces with one another, or the three plane angles, are called sides of the trihedral, and the angles of inclination, by way of distinction, simply angles. The three sides, as well as the three angles, are each called a part, so that the whole trihedral consists of six parts, and if any three of these be given, the remaining three can be found: therefore, if bodies constructed of stone, which are intended to have their solid angles to consist

of three plane triangles, the construction of such may be reduced to the consideration of the trihedral: as to the remaining surface, which encloses the solid, completely making a fourth side to the trihedral, it may be of any form whatever, regular, or irregular, or consisting of many surfaces; it or they have nothing to do in the construction. The portions of the trihedral, which may be obtained from three given parts, are the very same as the three found in a spherical triangle from three given parts: this is in fact spherical trigonometry.

This figure is easily comprehended by the plan, on which, in the form of the cross, the six squares that are to make the sides are set out. Q becomes the top, S one end, and P the other, R T the sides, and D the bottom. A piece of card-board, partly cut through, where the lines are drawn, may be folded on the contrary side so as to exhibit this figure. It will appear at once evident that each face has one opposite to it as well as parallel, and that the opposite edges are parallel; the straight line which joins two opposite angles passes through the centre of the cube.

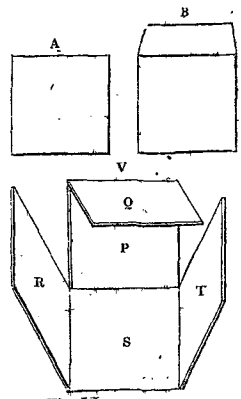


Fig. 857.

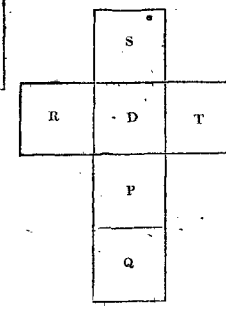


Fig. 858.

To draw and construct an Octaedron.—Trace the square N O P Q of the given dimensions: on each side construct an equilateral triangle, which being folded together will form one half of the octaedron; this repeated and joined to the first half constitutes the entire figure.

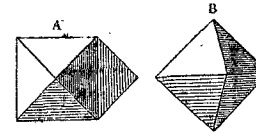


Fig. 859.

The equilateral triangle, the square, and the pentagon, are the only forms which enter into the regular polyedrons, whose angles and sides are equal; the solid angles of all, when cut away, regularly form figures, also symmetrical. The angles of the tetraedron may be so taken off, that we may obtain a polyedron of eight faces, composed of four hexagons and four equilateral triangles, forming a polyedron of fourteen faces.

When it is required to show a bird's-eye view of the octaedron, it may be drawn either in simple outline, or it may be shaded to express its figure. The square C D E F, by its dotted diagonals, shows the plan of its sides; G H I K L its solid form, and M the figure with its sides tinted.

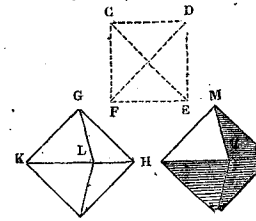


Fig. 860.

To construct the octaedron on card board, it is only necessary to cut partly through lines which unite the triangles with the side of the square, and then to bring them into the position shown at N O P Q, and uniting the edges R R to form one half, as T R. Similar operation for the other half V must then be performed, and the two brought base to base, to complete the model of the entire octaedron.

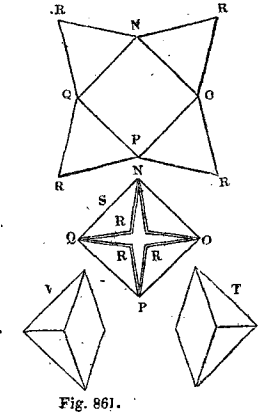


Fig. 861.

These regular solids have all been admirably cut by the aid of machinery, and are very useful in enabling us to comprehend the structure of minerals, or to project the form into which a stone requires to be shaped for particular situations in masonry. In the academy of the Greeks consideration was deservedly given to the five Platonic bodies, so designated after their great discoverer, who always taught by example or with models before him. In France great attention has been paid to the subject of projection, and to the right understanding of the regular and irregular solids; rules are laid down in every treatise upon carpentry and masonry to enable the student to perform these operations, and it is in proportion as he comprehends form, that he can construct with strength and economy. If it were necessary in the

Grecian schools to have a thorough and clear notion of form before an object could be rightly comprehended, it is equally so at the present day: let us remember what the artizans of Athens have left us, and then seek for the rules by which they were guided, and have before us the precepts of Plato in all our inquiries: that great philosopher in his "Phædo" observes: "If we are not able to find out truth, this must be owing to one of two reasons; either that there is no truth in the nature of things themselves, or that the mind of man is, from some radical defect, unable to discover it; upon the latter supposition, the inconstancy and uncertainty of human opinions can easily be accounted for, and therefore we ought to ascribe all our errors to the defectiveness of our own minds, and not to affirm, gratuitously, that there is any defect in the nature of things: truth is frequently difficult of access; therefore, before we arrive at it, we must proceed with great caution, examining carefully every step we take; and after all our efforts we shall often find ourselves disappointed, and forced to confess our ignorance."

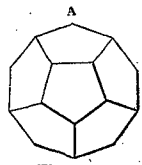


Fig. 862.

The Dodecaedron is formed round a pentagon in a similar manner, as C A.

The dodecaedron may have its angles so cut away as to produce a solid having twelve pentagons, united by twenty hexagons, and having altogether thirty-two sides; in this shape it nearly approaches that of the globe. A represents the solid resting on one of its angles.

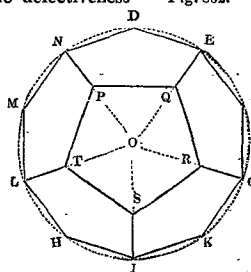


Fig. 863.

To draw the dodecaedron, describe first a circle of the dimensions to be given it, and divide it into ten equal parts, as shown at D E F G K I H L M N: these are to be united by lines, as shown in the figure; then from five alternate points, as E, G, I, L, N, draw other lines to the centre; then set out P Q R S T to show the pentagon at top, and omit the dotted lines to render the figure complete.

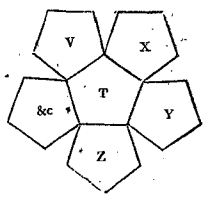


Fig. 864.

To construct the dodecaedron in card, draw first the pentagon T of the size or dimensions of the face; then on each of its sides construct the other pentagons V, X, Y, Z, &c. of the same size; then, after cutting through the lines partly by which the latter are united to T, they may be folded and united together to resemble half the solid, as shown at A; a similar process must be adopted for the other half, and then the two united to complete the dodecaedron.

The Icosaedron is formed by drawing twenty equal and equilateral triangles, and uniting them in a manner to form the figure Q, A, and B.

This figure is formed of twenty pyramids, whose bases are the twenty equal and equilateral triangles, the summits of which terminate in the centre of the body, as shown at A; this figure represents one half of the icosaedron, and the figure B the other. To draw this form, trace a circle of the dimensions to be given to it, and divide it into six equal parts, as shown at C D E F G H, then draw the sides C D, D E, E F, F G, G H, and H C, to complete the hexagon, in which is then to be inscribed the equilateral triangle H D F, and the parallelogram H D E G: then, from the point L, the centre of the side H D, raise the perpendicular L C, and from the same point L, draw the right lines L I, L K, to the points I and K, which are the points where the two sides H F and D F of the equilateral triangle H D F cut the side G E of the parallelogram H D E G.

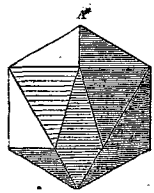


Fig 865.

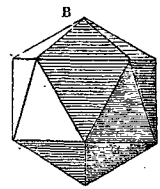


Fig. 866.

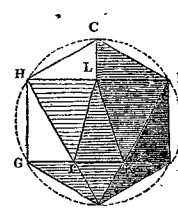


Fig. 867.

To construct it on card, twenty equal and equilateral triangles must be placed as shown at M N, and then, when the lines are partly cut through, they may be folded, as shown at Q.

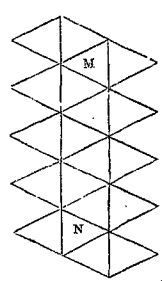


Fig. 868.

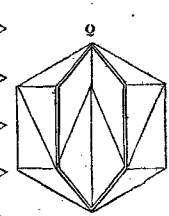


Fig. 869.

Cylinders are formed by drawing a parallelogram equal to its external face, and folding it together, adding the top and base.

A and B show two cylinders placed in a vertical position; and they are drawn by first making the circles B C and F G equal, and afterwards uniting them by the straight lines F B, C G, taking care that the centres E and D are in the same perpendicular line.

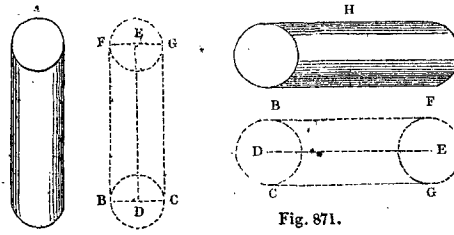


Fig. 871.

A cylinder lying in a horizontal position, as H, may be constructed around the centres D, E, in a similar manner; B F and C G being drawn to unite the ends.

Columns, which differ from cylinders by their *entasis*, or swelling at a certain part of their height, or diminishing like the frustums of elongated cones, may be formed in the same manner; their summits P and Q must, in that case, be made of the dimensions calculated for their upper diameters.

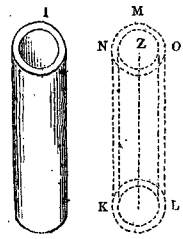


Fig. 870.

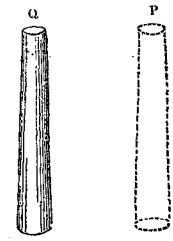


Fig. 872.

A hollow cylinder, or one constructed in card, is commenced by drawing the parallelogram R, which has its sides S T, V X, the length of its circumference, and those of X T and V S the height of the figure: simply bending such a card, and uniting its edges, completes the figure, and by covering the two ends with circular cards, formed of the proper dimensions, a solid cylinder may be represented. The cylinder is a solid figure, the surface of which is partly plane and partly curved, the plane portions being two equal and parallel circles, and the curved portion such that any point being taken in the circumference of either circle, the straight line, which is drawn through it, parallel to the line joining their centres, lies wholly in the surface.

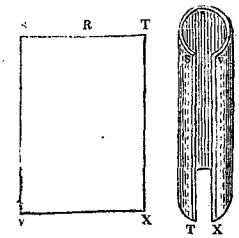


Fig. 873.

Right and Oblique Cylinders may be treated as prisms with polygonal bases. The setting out a right cylinder is obtained by having a rectangle of the height required, and also the circumference of the circle which serves for its base: the twelve perpendicular lines may represent the edges of a prism, and their distance apart is such that the whole bend round the plan is shown at the top and bottom. In the oblique cylinder, the same principles of setting out are attended to as already described for an oblique prism.

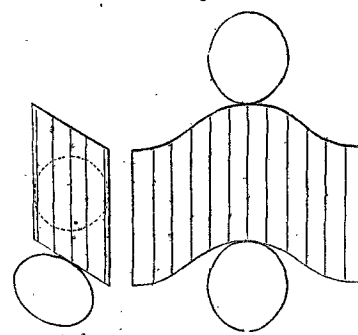


Fig. 874.

In making plans and elevations for the construction of an arch or vault, we may generally suppose that the vertical projection of a point is above the ground line, and that the horizontal projection is below: if the point be above the horizontal and before the vertical plane, its vertical projection will be above, and its horizontal projection below, the ground line: if the point be situated before the vertical and below the horizontal plane, the two projections will be below the ground line: if the point be situated above the horizontal and behind the vertical plane, the two projections will be above the ground line; and if the point be situated above the horizontal and behind the vertical plane, the vertical projection will be below, and the horizontal above the ground line.

To construct a mould for a cylindrical oblique arch terminating upon the face of a wall, in a plane at oblique angles to the springing plane of a vault, so that the coursing joints may be in planes parallel to the lines of the intrados of the vault, we must let the vertical plane of projection be perpendicular to the axis of the intrados, and conse-

quently it will also be perpendicular to all the joints of which their planes are parallel to the axis.

The vertical projection of the intrados will be a curve similar to the curve of the right section of the intrados. The vertical projections of the coursing joints will be radiant straight lines, intersecting the curved projection of the intrados. The vertical projections of all the joints, which are in vertical planes parallel to the axis, will be straight lines perpendicular to the ground line: the vertical projection of all the joints, horizontal planes parallel to the ground line.

In practice we may mould a cylinder to the form of the opening, which is to be arched or vaulted over, and after its ends have been cut to suit the faces of the walls with which it is to unite, we may make a correct model of this, and trace upon it the direction of each course, showing its plan and situation; or we may cover it with plastic clay, of a thickness correspondent with the first course of masonry, upon which we may define each particular joint, and thus arrive at a thorough knowledge of all the planes and their projections. Models at all times serve to help us to the right knowledge of form, and when correctly made, there is no difficulty in giving their representation upon paper, whatever may be their situation with respect to the plane on which they are to be drawn. The same principles apply to cones and all other figures, whether right or oblique.

Cones are constructed by describing a circle of a radius equal to its slant height, and then dividing the circumference into six equal parts; taking one of these parts, and uniting it together at the edge, the cone required is formed. When it is required to form a less acute cone, a greater portion of the circle may be taken, or that portion which equals the circumference of the base.

To draw a cone, either perpendicular to the horizon or reclining, a circle, G, must be first described, of the extent to be given to the base, as E F C D: G H must be set out of the required height, and the perpendicular drawn, after which the sides H F, and H D, H C, and H E.

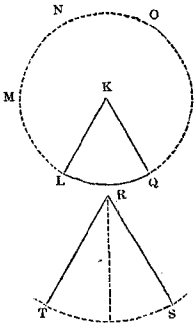


Fig. 875.

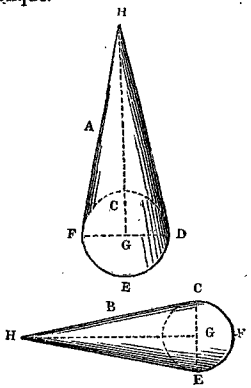


Fig. 876.

In France the *epure* made by the engineers and architects for the use of the workmen are of the size of the objects to be formed; these, corresponding with our working drawings, are set out with the greatest precision. The position of every part or its plane must be carefully studied before any figure can be worked. If in the cone X it were required to take out a portion, as that of T S in the cone Y, it is only requisite to set out upon the card of which it is formed the dimension T S on its outer edge, and then lines drawn to the centre, from which the curvature is struck, will represent the omitted part. By a similar method the conical covering of a tower or building may have developed upon it all the apertures or ornaments which form its decoration; which, when drawn upon the flat surface, will be in their true position after the card is folded together, if projected truly.

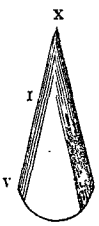


Fig 877.

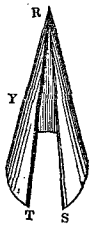


Fig. 878.

To cut out a piece of paper or card, so that it can be folded up into the form of an oblique pyramid: the position of the point must be shown on the plan or horizontal projection, which corresponds with the apex of the pyramid; from this point must be described the arc of a circle, upon which are to be transferred the horizontal projections of the inclined arrises: then on the perpendicular raised from the plan to the apex is to be set the height of the pyramid above the plane of projection; from a point so established, lines, as dotted, are to be drawn to their seat on the horizontal plane, which will show the real lengths of the edges of the pyramids: the small section shows the form at one-third from the top.

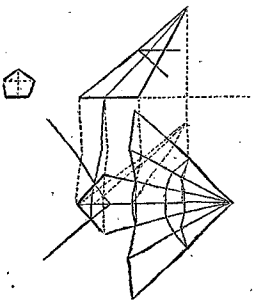


Fig. 879.

To draw an Oblique Prism, we must commence by tracing the profile of the prism parallel to the degree of its inclination: having defined the inclined axis of the prism in the direction of its length, and lines to show the surfaces by which it is terminated, upon the axis so drawn, the polygon which forms the plane of the prism is to be drawn perpendicular to the axis: thus the four edges of the prism will be obtained.

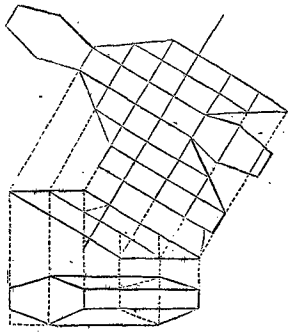


Fig. 880.

Right and Oblique Cones may be formed in a similar manner: thus the base of a cone is the sector of a circle whose radius is equal to the side, and the arc equal to the circumference of the circle which is its base.

If we regard the cone as a polygon with an indefinite number of sides, we shall have little difficulty in developing it; in the example we have shown twelve sides, and the lines may be imagined to show the edges or arrises.

The Cone may be formed by setting out its superficies, and bending it round until it unites at the edges.

The Base is a regular polygon, of an infinite number of sides, and consequently its development is the sector of a circle, whose radius is equal to the side of the cone, and the arc equal to the circumference of the circle which forms its base.

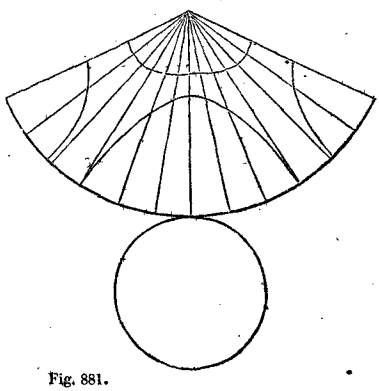


Fig. 881.

The ancients made considerable progress in the discovery of the properties of conic sections: Archimedes incidentally refers to the subject, but his writings do not explain the whole of the theory relating to it; he treats, however, of the areas of the sections, and the solids formed by their revolution about an axis; he also shows that the area of a parabola is two-thirds that of its circumscribing parallelogram, and this for a long time was the only true quadrature of a curvilineal space known. This great geometrician also pointed out what was the proportion of elliptic areas to their circumscribing circles, and of solids formed by the revolution of the different sections to their circumscribing cylinders.

Apollonius, the Greek geometer, cultivated the science of conic sections, and made considerable advances on the subject: before his time the different curves were defined by supposing right cones to be cut by planes perpendicular to their sides, by which method it was necessary to have three different cones to produce the three sections, as a right-angled cone for the parabola, an acute-angled cone for an ellipse, and an obtuse-angled cone for the hyperbola. Apollonius showed that the three sections might be obtained from any one cone, whether right or oblique.

In setting out a series of courses or zones on the cone, it is necessary to define all the divisions intended on the base, as well as on the slant lines, and then form each portion separately; where a cone is to be cased with masonry the thickness of the stone, when applied, forms an outer cone, consequently two developments are required.

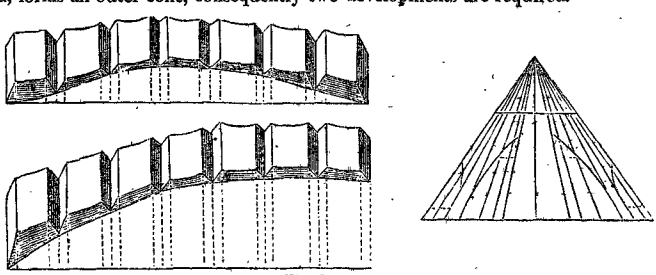


Fig. 882.

Upon a cone so set out may be traced the varieties of curves or sections which produce

the ellipsis, hyperbola, and parabola, so useful in the study of conic sections, or in the development of mouldings used by the Greeks. The base of the cone may be divided into a number of equal parts, and from each point on them lines may be drawn to the apex, and either of the above-named figures may thus be portrayed.

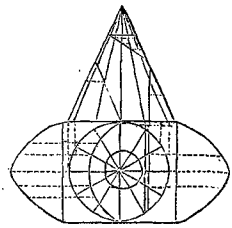


Fig. 883.

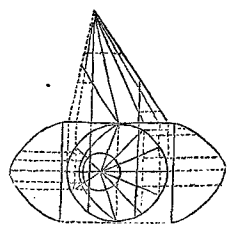


Fig. 884.

To set out an oblique cone, the position of the apex must be found on the plan, and the same method of proceeding must then be adopted as in the preceding example: after the seat of all the lines has been found upon the plan, and their respective heights set out on the planes which represent the vertical, they may be transferred to the figure.

Globes are constructed by drawing the parallelogram E F G H, which has its greater side E F twice the smaller one E H. Divide the small sides E H and F G each into two equal parts in the points I and K, and draw the line I K; divide this length into twelve equal parts, and prolong it at pleasure. Take nine parts from the twelve on I K, and placing one foot of the compasses on any division, as 7, observe where the other foot cuts the line I K, as at L: from the point L as a centre, with the radius L 7, describe the arc M 7 N: then with the same radius L 7, placing one foot on the point 6, observe where the other foot falls at O, and from this point O as a centre, with the radius O 6, describe the arc M 6 N, which will form the spindle M 7 N 6. Twelve of these spindles made with the same radius, and according to the same rules, cut and folded together, will form the globe Q.

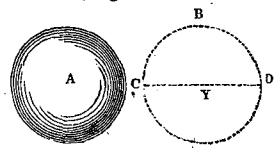


Fig. 885.

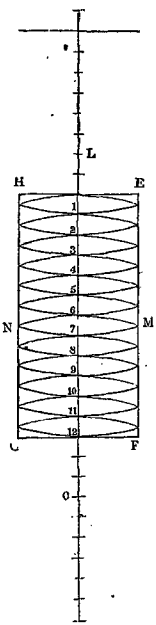


Fig. 886.

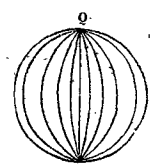


Fig. 887.

When it is required to cover a dome or any portion of a globe, these spindles or gores must be carefully drawn, and if the boarding or material is to be applied from the base towards the top, the diagram will show the method for cutting it out; if it is to be bent round, so as to exhibit horizontal joints, the several portions will be those of cones, as already described. Timber domes are frequently formed by adopting both processes, and many upon a small scale exist in Italy, hooped round with thin board, the first formation being that of a number of gores, cut as shown in the figure E F G H; three or four thicknesses of bent plank screwed firmly together will form a dome of sufficient strength to sustain a covering of lead or copper, and, when assisted by an iron hoop at the base, will endure a considerable weight without yielding.

When the base of a dome is polygonal, the forms to be given to the gores may be easily found by a similar process.

To project a Sphere orthographically on the Plane of the Equator: the centre from which the circle is struck that represents the equator will be the projection of the pole; and the two diameters which are perpendicular to each other will be projections of meridians 90° distant from each other: each quadrant of the circle must then be divided on its circumference into six equal parts, and lines drawn as radii from these points will be the projections of meridians of 15°, 30°, &c. &c., dividing the equator into twenty-four equal parts, any one of which may be assumed as the first meridian. To project the parallels of latitude, divide one of the quadrants into nine equal parts, and drop from the points of division as many perpendiculars, which will cut the diameter of the circle; then from the pole as a centre, describe other circles through these points on the diameter, which will be the projections of parallels of latitude at the distance of ten degrees.

By a series of parallel circles, crossed by others perpendicular to them, we may form a

sphere into a polyedron, and these bands can be made to exhibit the faces of the truncated pyramids of which they are a portion.

The mineralogist has taken the *regular tetraedron*, the *cube*, the *rhombic dodecaedron*, the *octaedron*, the *six-sided prism*, and the *parallelopiped*, as the primary forms upon which the several crystals are found: in the first four, which are called the regular geometrical solids, we find all the planes of each equal and similar; the cubical crystal of fluors may have each of its solid angles removed easily, when its figure will exhibit eight triangular smooth planes instead, and then continuing to remove the several layers which compose these eight triangular planes, we arrive at the eight triangular planes of a regular octaedron. By a study of the structure of a mineral substance, we shall arrive at a tolerably good idea of the principles of descriptive geometry: the sphere may be in the present instance considered the nucleus upon which the parallel deposits are formed.

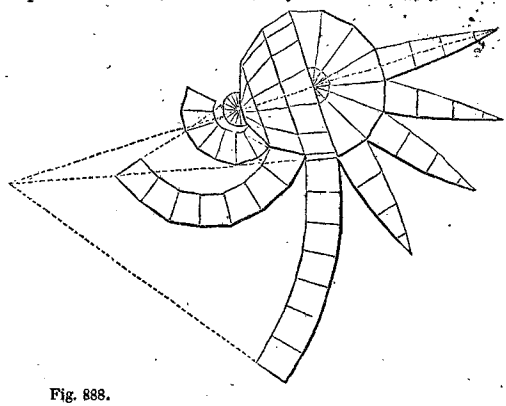


Fig. 888.

The sphere is a polyedron, having a great number of plane faces, formed by truncated pyramids whose base is a polygon, and its development by conic zones is obtained in the same manner as for truncated pyramids, with this difference, that all the arrises are arcs of circles, described from the summits of cones, instead of being polygons.

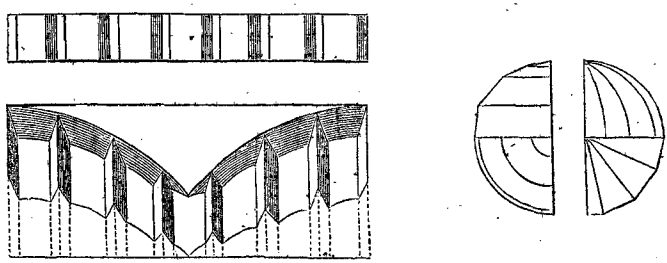


Fig. 889.

On Shadows.—That part of a body from which light is intercepted by any object intervening is said to be in shadow. The rays of light, which we receive from the sun, proceed in straight lines, and opaque objects, not transmitting through them the light they receive, necessarily have their opposite sides to the luminary in shadow: a shadow becomes apparently darker as the illuminating powers which produce it are increased. A stream of light may be supposed to proceed from every luminous body which falls on all the objects around, and is again reflected by them to others, until it is entirely imperceptible.

Shadows are produced by depriving the object of the direct rays of light, and the artist generally represents on his drawing a shadow equal in depth to the projection of the object which casts it, or at an angle of 45°.

Light is either transmitted, absorbed, thrown back, or reflected, and the latter is always so thrown that the angle of reflection is equal to the angle of incidence.

Some colours reflect light stronger than others, and on this subject the painter must carefully study nature to obtain his knowledge; in a lofty building those parts nearest the ground receive the greatest portion of reflected light, and the upper the less, consequently they are darker: and the strength of colours is heightened or lessened from this cause. All shadows thrown from one object to another are darker than the object itself, and those parts which do not receive the direct light receive their brightness from reflection, and the shadow gets no reflection except from the object in shade.

The cornice of a building, which casts a shadow on its perpendicular face, receives on its under side or soffite a proportionate quantity of reflected light, either from the ground beneath it or the upright face of the wall; consequently it is not so dark as the shadow it casts, and hence the beautiful relief between one and the other: there is the positive light, the intermediate, and the shadow.

All Opaque Bodies which are lighted up on one side cast a shadow on the opposite; and those which receive their light from bodies larger than themselves cast a shadow as at A;

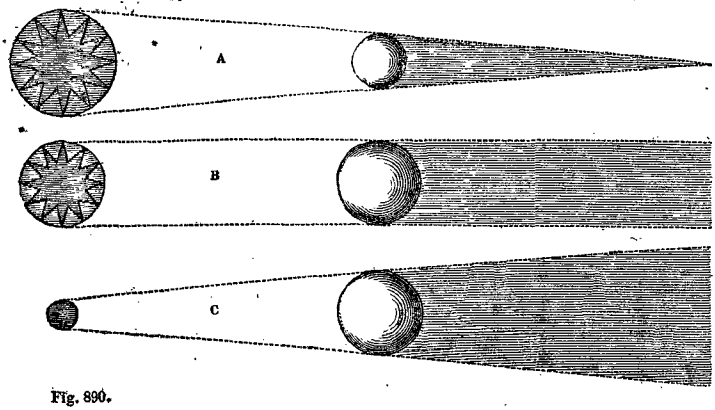


Fig. 890.

those that are of equal magnitude as those at B, and those that receive their rays from a smaller light, as that of a candle or lamp, as shown at C.

All luminaries, as the sun, emit a stream of light by which objects are rendered visible, and those bodies which cannot be penetrated by it are called opaque bodies: the part which is deprived of light, or which does not receive it, is said to be in shade, and that part of any surface on which a shade is projected is called the shadow.

The side of the body, as that of a prism, which is not opposite the light, is that which is in shade, as A K. Should the top of the prism receive the direct light, then the side K ought to have a teint, to distinguish it from the face which is so strongly illuminated: but if the rays fall at an angle of 45 degrees, the horizontal and vertical faces which receive them may be supposed equally bright.

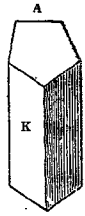


Fig. 891.

Sciography, or the principles upon which shadows are projected, will be the better understood as we advance in our knowledge of descriptive geometry, which explains as well as removes all the difficulty of understanding the position of the several planes, or their relation to each other: as the rays of the sun are reflected in all directions, the projecture of the prism prevents a part of the reflected rays from proceeding to the plane behind the prism, and consequently that plane would be a little darker than the face of the prism which is parallel to it; but as the side of the prism adjoining to the plane will throw a reflection, it is difficult to distinguish any difference between them. The difference of light between the side of the prism which is perpendicular to the plane and the plane depends on the position of the luminary; if its plane be equally inclined to both, there will be the same light on each; but when it is more inclined to one than the other, then that which is the most oblique will be the darkest.

In a cube that is doubly inclined, as in the figure, its projection upon a horizontal plane is a regular hexagon, and upon a vertical plane a rectangle; thus showing the variety of shadows such a solid may cast. By dropping perpendiculars from the solid angles of the cube, we may, upon the horizontal plane, where the hexagon is shown, set out the seat of every portion of the cube which is obliquely placed above: by parallel lines we describe upon the vertical plane the quadrangular figure which the cube exhibits, and which is similar to a section seen diagonally. In stone cutting, as we shall hereafter find, it is highly important that we understand the form of a cube in every position, and this is only to be exhibited by imagining a variety of planes, upon which the figure may be drawn: the cube may be made to contain the sphere or portions of it, the planes of which can be found in every direction, and afford the student an opportunity of study and practice in drawing.

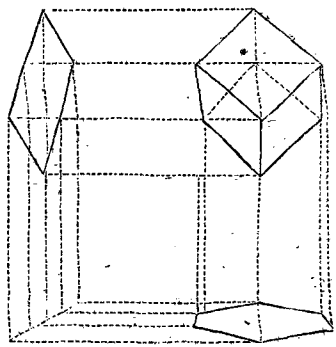


Fig. 892.

It is not possible thoroughly to comprehend the seat of a shadow upon either a vertical or horizontal plane, without using the methods already described for projecting them: by the various positions in which the cube is placed, we can perceive that its shadow is dependent upon the same principles as those already described for the formation of a solid.

The geometrical form of the cube, shown in the figure, would be as here represented.

The diagonal lines dotted on the plan show the position of the upper edges of the cube; the perpendicular dotted line on side projection shows its diagonal: by a variety of inclinations the projections of the cube may be made to exhibit the parts of machinery, for on every side may be drawn a wheel or other figure, and its projection found either upon the vertical or horizontal plane.

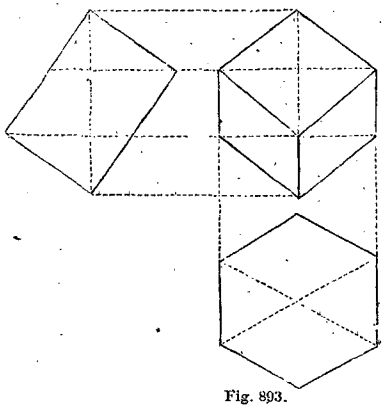
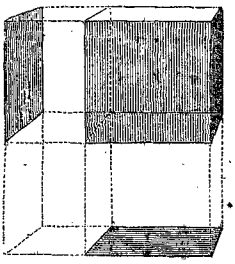


Fig. 893.



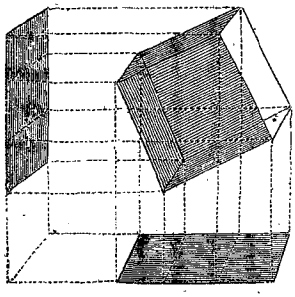


Fig. 894.

A sphere or ball, whether its projection be on a vertical or horizontal plane, is always found to be circular.

To project a curved line, when the surface in which it lies is curved, and it is not perpendicular to the plane of the projection, it is better to form a polygon, and then from each of its angles to drop a perpendicular, from which parallel lines may be drawn to the chords which subtend the arcs. But as the curved line has a double flexure, it is necessary to inscribe within it another polygon, which shall represent the surface in which the curved line is situated. If the plane on which the shadow of the globe is represented was not in perspective, the form of it would be circular; its diameters in every direction being the same, so must be that of its shadow.

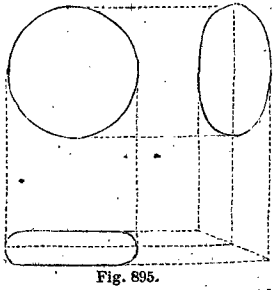


Fig. 895.

The cone, when projected upon a perpendicular face, assumes the character of the pyramid, and on the horizontal plane the circle. The projection of any of these figures is exceedingly simple, and needs but little further observation.

In the shadow of the cone the same rules must be adopted, the seat having been found on the horizontal can be readily, by means of parallel lines, transferred to the vertical; the direction of the vertical plane does not alter the height of the projected shadow, though its breadth depends upon its position.

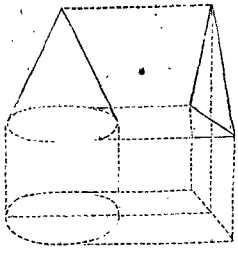


Fig. 896.

The shadows of curved lines being projections of those curves, they may be treated as such: that of a circle, in any position where the luminary is not in its plane, will be a conic section if the shadow be received on a plane, and the form of the curve, which will represent it, will depend on the relative position of the circle, the luminary, and the plane of the shadow; therefore the shadow of a circle can only be obtained by establishing a sufficient number of points in its curve, and then drawing lines through them. To find the shadow of any point it is ne-

cessary to fix its position on the plane of the shadow, and this can only be effected by the ordinary rules of projection: if we regard the cylinder of rays which produces the shadow of a circle as a solid capable of being cut by a plane in any direction, we shall find no difficulty in fixing the points of each ray upon the plane so cutting it, and through them tracing the form of the shadow.

A pyramid may be projected on a plane or upright wall, by continuing the lines of its base, and then drawing perpendiculars to them.

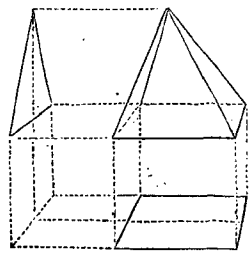


Fig. 897.

The figure more clearly shows the orthographical projection on two planes at right angles with each other, one of which is termed the horizontal, the other vertical: it simply depends upon representing a point on any space by drawing a perpendicular from it to both the vertical and horizontal planes, that on which the perpendicular falls being termed the projection of the proposed point; if we then imagine lines made up of points, we shall have no difficulty whatever in projecting the entire outline of any figure.

We may suppose the figure to represent a building, and if it be required to show the position on the plan of the tiles or slates with which it is covered, we have only to drop perpendiculars from them to the plane below, and find where their lines intersect: the apex of the pyramid, which may be the point of a hipped roof, would fall where the diagonals of the square cross on the plan below; it is therefore not difficult to transfer the seat of a point from one plane to another.

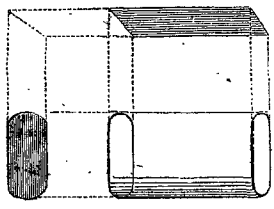
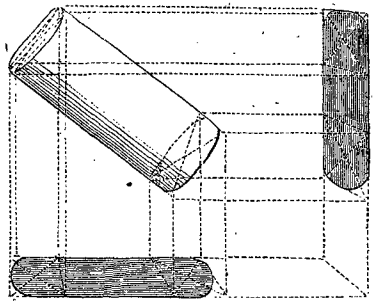


Fig. 898.



In the cylinder it is necessary, before we can project it, to imagine its surface covered by a system of lines or a series of points, after which each may be projected to a vertical or horizontal plane, and when these are united by lines, the figure will be projected. Cylinders may be regarded as prisms whose bases are either circular or elliptical, and these may be resolved into polygons which have straight lines for sides, uniting in as many points.

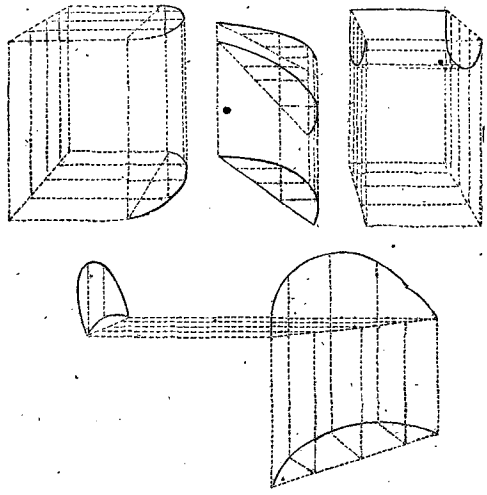


Fig. 899.

Solids, which have a double curvature, require that we should consider them as inclosed within a single surface, and as such bodies present neither angles nor lines, they must be represented by some apparent curve which will bound their superficies: this may accurately be shown by a series of tangents made parallel to a line drawn from the centre of the solid, perpendicular to the plane of projection. When such solids are cut by other planes, we must by points and lines find their true figure upon them.

And the ring L B, which has its face in shade, casts a circular shadow on the ground, which is darker than the object that has defined it: the globe M C receives its light in front.

In a polygonal or circular ring, the boundaries of light and shade may be accurately defined, by having its ichnography and elevation properly drawn out. If the seat of the sun's rays be drawn on any plane, on which a cylinder is laid, with its axis perpendicular to the seat and parallel to the plane, the lightest line on the cylinder will be nearer to the plane in this position than in any other; but if the axis of the cylinder make oblique angles, then the line of light will be higher on the cylinder. And, should the axis of the cylinder be parallel to the seat of the sun, the lightest line on the cylinder will be at its greatest distance from the plane: these rules cannot be so well understood as by a reference to the model of a polygonal ring laid in a position to receive the sun's rays, and then its several planes may be traced geometrically, and the principles of light and shadow rendered clear.

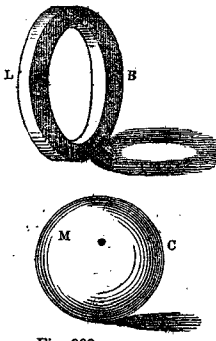


Fig. 900.

In shading the globe, we must first consider the point upon which the rays of light directly fall, and then gradually diminish its effects until the shade commences. But we must not forget that the outer edges receive a reflected light, and that no part of the surface which bounds the figure is black. When the sun's rays fall upon a reflecting plane, the angles made by them will produce reflected light, which is received by every part of the object within its influence: the globe standing over a sheet of white paper would consequently have all its under side illuminated and rendered brighter. To project its shadow it is necessary to draw out the several planes, and pursue the course adopted in descriptive geometry.

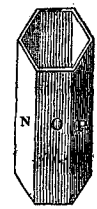
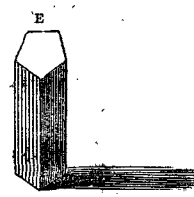
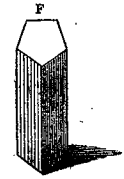


Fig. 901.

As the light of the sun falls perpendicularly or from above, the top edges and the interior of a hollow body will receive a portion of it, and the sides N, O, P will be of different shades, as they are more or less removed from the position to receive the direct rays of light.



E, F, D, will show the ordinary manner of shading solid bodies, the light being presumed ordinarily to proceed from the left hand, and where two objects are shown, as H, I, their several planes which are on the same parallels must be shaded in the same manner. As the rays of light proceed in straight lines, every opaque object on which they fall throws a shadow on the side opposite the luminous body; and this shadow is darker in proportion as the illumination is stronger. Shadows are either *right* or *versed*, according to the position of the planes which receive them: that which is thrown by an upright body, as the prism which is projected on the plane of the horizon, is a right shadow; that on a vertical plane, as a beam fixed perpendicular to the face of a wall, is a versed shadow. In both instances the length of the shadow is to the height of the opaque body, as the cosine to the sine of the angle which the luminous ray makes with the plane. The altitudes of objects may be thus taken by measuring the shadows they produce, and which was frequently done by the ancients.



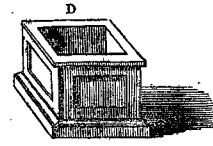


Fig. 902.

Sciography, or the science which teaches the projection of shadows, has been very successfully studied by many artists, and it will only be necessary to allude to a few more simple architectural forms to make the subject perfectly clear.

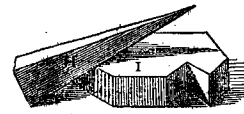


Fig. 903.

A cylinder, having an abacus or square tile laid upon it, would, when the sun is at an angle of 45°, form a shadow in depth equal to its projection. A line drawn from the centre to the angle of the abacus is the seat or plane of a ray of light; perpendicular lines represent the surface of the cylinder, and when parallel lines to the rays of light are projected and made to intersect with those that are perpendicular, the points of intersection express the extent of the shadow, and a line drawn through them indicates it.

When the abacus is circular, then the cylinder beneath it will receive its shadow in the same manner; the process of projecting it is the same as in the preceding example. A prism with a polygonal base and a projection breaking round its top, when attached to a wall, will cast a similar shadow; it will not be difficult to cast the shadow upon the base, shaft, and capital of a column, if we suppose them to be cut into planes parallel with its axis, for the purpose of marking the points which receive the shadows; for it must be evident that if a ray of light enter any of these planes, every part of that ray will be in that plane, and the projecting parts upon the edges of those planes will cast a shadow at the several points of intersection.

In shading mouldings, it must be remembered that where the end or side of a building on which they occur is in shade, they will not receive any reflected light, either from the ground or the surface of the building: and such mouldings will have a contrary effect to others in shadow, situate on the light side of an object.

An ovolo laid level, whose greatest projection is above, when on the dark side of a building, will be lightest above, and gradually becoming darker towards its lowest edge.

The cavetto will be the reverse of this when in the same situation; it will be continually lighter and lighter towards the under edge.

Perspective is the art of drawing the forms of objects as they are seen: this method of delineation differs materially from that called geometric, and is in fact the section of a pyramid of rays, proceeding from the object to the eye; suppose for example a line drawn from every point or angle of a cube to the eye, or threads substituted for such lines, and that they in their passage pass through a transparent plane, as a sheet of glass or paper; the holes made in this plane will indicate the boundary and form of the object, and consequently its perspective representation.

Vignola, Seragatti, Brook Taylor, Priestley, and the Maltons, have by their writings rendered this subject perfectly clear, and the Young Painter's Maulstick by James Malton is an admirable practical treatise; and Sir Joshua Reynolds, in the first Discourse he delivered at the Royal Academy, showed its importance: for it had been by many supposed to bound the artist with laws that might cripple the beauty of the forms he was called upon to draw, but the President emphatically stated that "Every opportunity should be taken to discountenance that false and vulgar opinion, that rules are the fetters of genius; they are fetters only to men of no genius; as that armour, which upon the strong is an ornament and defence, upon the weak becomes a load, and cripples the body which it was made to protect. How much liberty may be taken to break through these rules, and as the poet expresses it, 'To snatch a grace beyond the reach of art,' may be a subsequent consideration when the pupils become masters themselves: it is then where their genius has received its utmost improvement, that rules may possibly be dispensed with: but let us not destroy the scaffold until we have raised the building."

To the civil and military engineer a knowledge of the rules of perspective is highly important, to enable him correctly to delineate all the objects within his sight, and to all it is the principles of the art of seeing, and should be generally understood.

Drawing is as useful as the art of writing, and oftentimes the pencil in the hand of an experienced draughtsman can explain more than the pen of a ready writer: and in giving directions to a workman, a drawing accurately made is often all he requires; to those who are desirous of forming a clear and distinct notion of form, the study of perspective is necessary, for every thing we see is seen perspectively, and no object appears as it really is from any one point of view except it be the sphere.

In the geometrical representation of a building all the forms are drawn exactly as they are, and it is necessary that such drawings should be made before we can exhibit its perspective effect.

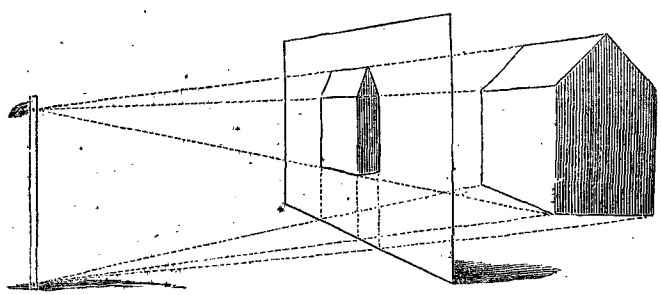


Fig. 904.

A visual ray is an imaginary line extended from the eye to any particular point, and a

number of these rays is called a pyramid: to find the perspective of the small house in the accompanying figure, it is only necessary to find the points of intersection of the visual rays, made with the visible angles of the object as they pierce the plane which cuts them.

The point of view or point of sight is the eye of the observer.

The plane of delineation or picture is the canvass or paper upon which the subject is drawn.

The original object is the house or any other to be drawn.

The original lines are the boundaries of the original objects, or of planes in those objects.

The horizontal planes are any planes placed truly level, that is, to which the plumb line is perpendicular.

The horizontal line is a line on the plane of delineation level with the eye of the observer, or point of view, and is supposed to be obtained by a horizontal plane passing through the eye of the observer produced till it cuts the plane of delineation.

Vertical planes are planes perpendicular to horizontal planes.

Ground plane is that upon which the objects to be drawn are placed, and also that on which the observer stands.

Ground line is that on which the plane of delineation rests on the ground line.

Station point is that on the ground plane perpendicularly under the point of sight or point of view.

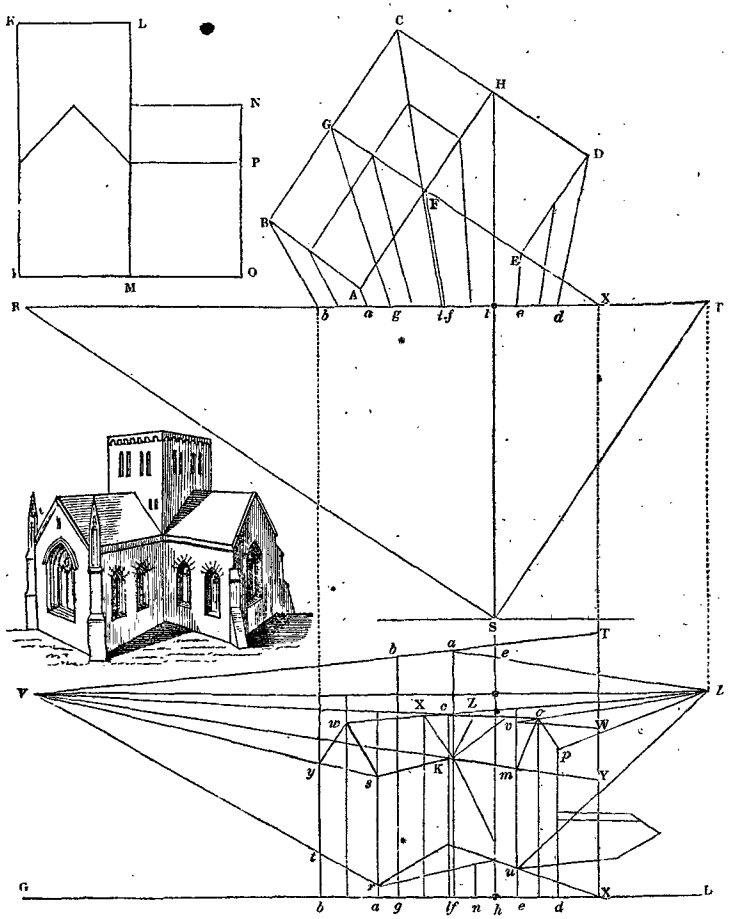


Fig. 905.

Vanishing point is a point on the plane of delineation, which is the point of union or

point of convergency that two or more lines will have, which are the representations of two or more parallel lines in an original object, placed inclined to the plane of delineation.

Vanishing line is a line on the picture or plane of delineation supposed to be obtained by a plane passing through the eye parallel to any plane in an original object, and produced until it cuts the picture: the horizontal line is, therefore, the vanishing line of all horizontal planes, and all horizontal lines have their vanishing points in the horizontal line.

To find the vanishing point of a line as well as all the others, the diagram introduced may be sufficient.

The plan of a church is shown at A B C D E, and at the side an elevation on which the several heights are drawn: it is required to put this in perspective on a plane or sheet of paper, standing vertically on its edge upon the ground line, R T, the situation of the draughtsman being at S, the station point. S T and S R are drawn parallel to the ends of the building through the station point S: and where they cut the ground line, R T, they fix the extent of the vanishing point. The line V Z is the horizontal line, and perpendiculars dropped upon it from the points R and T determine the vanishing points V, Z.

On the plan, F E and F A are prolonged to the ground line R T: these dropped serve to set out the heights of the several parts: X Y is the height O P, which, when drawn through to its vanishing point, V, marks *um*, as the perspective height of the same line: X W shows the height O N, which is also drawn through the vanishing point in the same manner, and where it cuts the prolonged perpendiculars *um* at *v*, a line is drawn to its vanishing point *z*, and at *o* is found the point of the gable of the roof.

Lines having been drawn from the points A, B, C, D, E, F, G, H, of the plan to the station point S, the corresponding small letters on the ground line R T show where the perpendiculars are to be dropped, on which the several heights are to be perspectively marked off. *mopqu* show the end E D: *ikmu* the side E F, *rski* the side A F, *rsyt* the end A B. O O is the height of the spectator, which, of course, may be varied at pleasure, and were the horizontal line V Z dropped to half the height, the perspective representation would be varied materially: the top of the tower *bae*, as well as the ridges *wx* and *oz*, would then all incline downwards towards the vanishing points, Z, V, which are supposed to be immediately over the points R T of the ground line.

Sometimes, to enlarge the perspective representation, the lines are not drawn immediately to the station point, but are prolonged upon the ground line, and then crossed to the vanishing points, which have been previously found. In this example we have the effect of the capital above and below the horizontal line, and the small letters show the position on the plan, and the corresponding large ones; those of the plan above and elevation are shown in perspective.

For convenience the plan to be put into perspective may be placed either above or below the line, and in the diagram three systems are shown of drawing a figure; the angle of vision or angle of view being the same in all.

The Young Painter's Maulstick contains, among many other valuable hints, one with regard to the best angle for vision, or that within which objects should be viewed, so as to obtain the most agreeable representation; for as the angle of vision is enlarged or lessened by viewing the objects near or remote, their appearance will be altered. Objects may be placed too near the eye for their proper observance, and as the eye can contemplate only a point at one time, it is by its celerity and continual motion that it becomes perfectly sensible of a whole or of many forms; but when an object, or many objects widely extended, are placed too near the traverses of the eye, to contemplate them becomes painful. In taking a view of a building turning the head should be avoided, as no view should comprise a greater extent than the eye can agreeably contemplate at one glance, or that can be seen by a pleasing and satisfactory traverse of the eye alone, which necessarily confines the extent of the matter, and of course the angle of vision, to certain limits. The eye rests with composure on what it can contemplate with little trouble; not only too great an extent, but too many objects, however they may interest and delight at first, soon distract and tire the organ of vision. Smallness of object has nothing to do with the angle of view; a cube or miniature being placed too near the eye may form a large angle of view, and cause pain in observing it: a large extent of view, or a large picture, may be contemplated with as much ease as a small one; it is only to place the observer at a greater distance.

Isometrical Perspective is sometimes used to represent buildings, and is of great use in diagrams and drawings of machinery, as all perpendicular lines in them may be measured by a scale; the principles may be explained in the representation of a cube, into which figure all others may be resolved.

The square or side of the cube is crossed by diagonal lines, and then another, as A C, is set out from A D, at an angle of thirty degrees; and where this cuts the other diagonal, as at B, you have the length of the side, as A B, for the radius of a circle which is to contain the isometrical cube; and if on this a scale is marked, all other parts may be measured by it. The sides, as well as radius and height in the figure, all exactly correspond in length, and,

consequently a straight edge or ruler, with a triangle having angles of 30, 90, and 60 degrees, will enable us to set out or subdivide a cube into any number of parts.

The cube is contained in a circle, and its centre becomes one angle of the upper face: lines drawn from the angles of the hexagon indicate the whole of the sides. One quarter of such a cube may be shown as extracted or cut out by dividing the sides into two, and raising three perpendiculars; or it may be represented as seen from the other angle.

A mortise and tenon, or groove and tongue, are easily set out, as is a Greek cross, or three steps. By cutting a cube into a series of planes the interior of a building may be represented, and a scale applied, and in this example three sections are shown, which may be supposed 100 feet in width, and the same in height; consequently 50 feet apart. Two others intervening would have been more in unison with the proportions found in churches, and could be easily introduced by dividing the side of the cube into four instead of two, and repeating the method here laid down of drawing the respective lines.

Where wheels are to be shown they must first be inclosed within a square, and then there is no difficulty in representing any combination of them. For minerals this method of drawing is very useful, and is becoming general.

Curved lines and surfaces may be illustrated by this system and shown with great accuracy; suppose in the upper square we were to trace a circle, and beneath it in the lower plane another, of similar dimensions: uniting these by drawing two perpendicular lines, we have the representation of a cylinder; between the planes which express its top and bottom, we may have any other number we require by setting out parallel

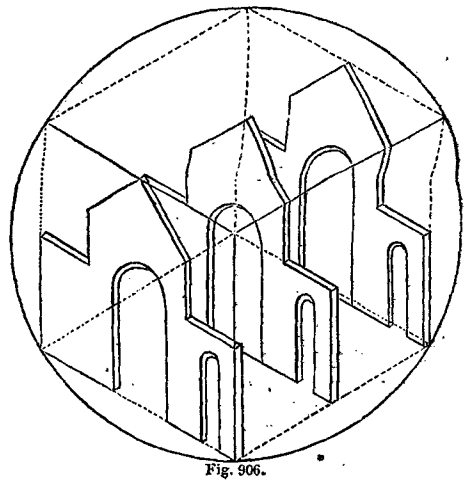


Fig. 906.

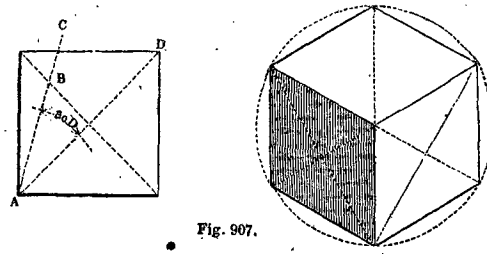


Fig. 907.

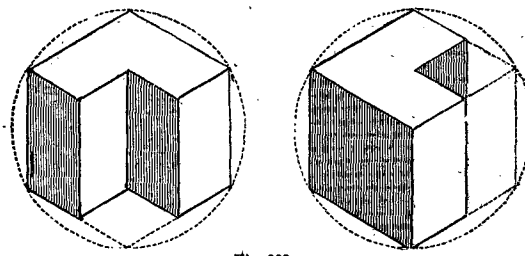


Fig. 908.

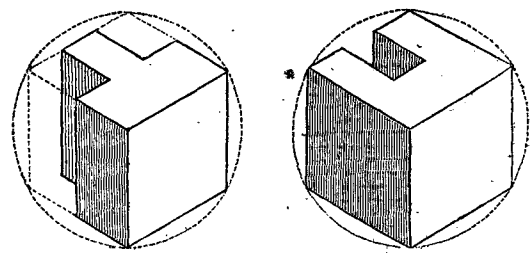


Fig. 909.

squares with inscribed circles.

The cone may be shown inverted by drawing two lines from the circumference of the circle on the upper plane to a point in the centre of the lower; or it may be exhibited on its base by making the apex terminate in the centre of the upper square, using the lower circle for its base.

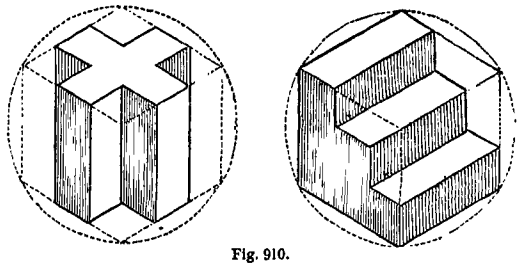


Fig. 910.

Setting out Points or Lines.—To set out lines on the ground, where the situation is inaccessible, as supposing it were required to draw through the point A a line parallel to the inaccessible wall B C. Unite two straight edges or rulers about 3 feet in length by a screw, on which they could be made to open and shut like a pair of compasses. Place the end of this instrument against a piquet at A, and bone along the edge of the two rules, and open them until they cut the inaccessible points B and C; then secure the opening of the two rules, by screwing on a cross piece which shall embrace the two arms.

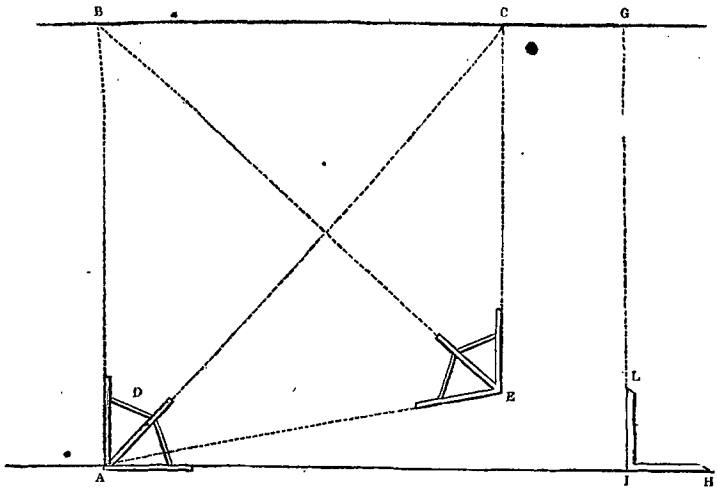


Fig. 911.

Then changing the position, walk to the side through which the parallel is to be drawn, looking along the two open arms of the rules till B C is seen, which will be the case when the station E is arrived at.

Then removing the transverse rule from above the two others, and placing their head on the piquet E, open them, so that by boning along their sides the point B and the piquet A are discovered, and by which the angle B E A is obtained; this being found, fix the rules, and proceed to the station A, so as to see the point C along the limb of the angle B E A. Then a cord drawn along the other limb at F will be the parallel to the wall required.

If it be required to let fall a perpendicular from any inaccessible place, as at B, from the point G, first mark out the parallel line, and then, by means of a square L I H, advance along the line, till the boning edge of the perpendicular comes opposite the point G.

Of Levelling and Levelling Instruments.—To the architect, as well as the civil engineer, this term is understood rather to mean the difference which exists between two planes or heights than the idea of a perfectly horizontal surface; the object generally being to discover how much ground must be elevated or removed to facilitate the running of water, or the construction of a railroad over valleys or mountains. A level line infers a plane or surface parallel with the horizon of the place where it exists; so that if water were placed upon its surface, it would remain at rest, having no inducement either to mount or descend.

But in reality when we look at a distant object, our eye is in the direction of a tangent to the surface of the earth, which is not the true level; this follows the earth's curvature, and in constructing a canal the bottom should not be a straight line, but concentric: any drops of water placed in succession upon such a curved line, from their being equidistant from the centre of the earth, will remain in the position in which they are placed.

In the levelling for the foundation of a building where the dimensions are small in comparison to the circumference of the earth, they are generally treated as straight lines, and in practice this is sufficiently accurate; but all plummets gravitating towards the earth's centre, it stands to reason that a succession of lines taken with the common level must be polygonal.

Telescopes, used to distinguish distant objects, consist of a number of glasses placed in a cylindrical tube, with their centres in a straight line.

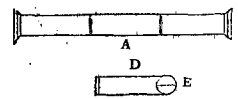


Fig. 912.

The Eye-Glass is placed in a small tube, which can be drawn out, and adjusted to different observations, and it has in its focus a thread marked E, which serves to regulate the sight.

The Object Glass, at the other end of the telescope, is shown at C.

The Optical Axis is the line proceeding from the eye when looking through the glasses, and which passes through them at right angles. The glasses are spherical, and of a convex form, their centre being thicker than their edges.

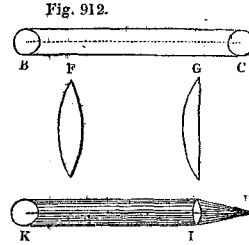


Fig. 913.

The Focus of a Glass is the point in which the rays reflected from an object, having passed through a glass, unite in a point. In practice it is highly important that the cross hairs in the telescope should be properly adjusted, which is done by attaching them to a brass ring, and the eye tube must be drawn out until these hairs appear to occupy the focus of the glass, and can be distinctly seen. The telescope has a screw attached to the instrument, on which it rests, and which elevates and depresses it in a manner to be directed to any object. The horizontal hair in the telescope being in apparent contact with the object, the vertical one must be treated in the same manner until it also cuts it.

The Spirit Level with a Telescope is made of brass about 12 or 18 inches in length, sometimes of a cylindrical form, and at others that of a parallelogram: it encloses a telescope D E, in which is a tube F, having an eye-glass, with a thread fastened in its focus, and which draws out to suit the various sights: at the other end of the telescope the object-glass is inclosed in a small frame, and which can be moved either up or down by a screw. This telescope is placed in the tube B C in a manner that it can be turned on its

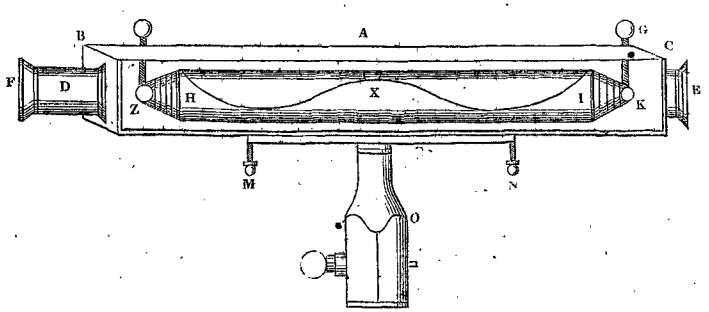


Fig. 914.

axis half round, and back to its original position: against one side of the tube B C the spirit level H is attached at its two ends by the screws K and H; at H are two rings, one of which clasps the tube, and the other end is attached to the screw L, by which the level H I can be elevated or depressed at pleasure, so as to make the level agree with the visual ray of the telescope: below the square tube B C is a plate of brass, which can be elevated or depressed by the screws M N; to the centre of this plate the joint is attached, by which the level can be turned in any direction, and roughly adjusted.

To centre the Telescope, it must first be mounted on a stand, and pointed towards the object, in order to observe where the thread of the telescope cuts, and which need not be on a level

with the instrument. Then the telescope must be turned half round, or the other side upwards, in order to see if the thread cuts the same point; if it does, it is sufficient proof that the telescope is properly centred, and has its sight parallel to the points of support; but if this point of sight or visual ray cuts above or below, then the screw must be turned which elevates or depresses the object glass, until the visual ray coincides with an intermediate point, and then again reverse the telescope, to see if it is properly centred.

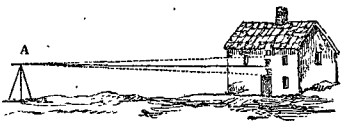


Fig. 915.

To rectify the Level, or to make the spirit level attached agree with the telescope, two piquets, as G and H, are planted not more than 300 feet apart; then from the station G observe the piquet H, the spirit level being adjusted until the bubble of air is in its centre, as at K; the card I must then be raised or lowered until it coincides with the visual ray of the observer at G. The observer at G must then place against his piquet another card K, at the height of his eye; when looking at the card I, he must then move the level to the piquet H, and place it horizontally at the same height as the centre of the card I, to observe the piquet G; then if its visual ray coincides with the centre of the card K, it is a proof that the visual ray is parallel to the horizon, and that the level is rectified. But if it happen that the visual ray cuts above or below the centre of the card K, as in the figure shown at L, then keeping the eye at the same height, lower the telescope until the visual ray cuts an intermediate point, as M; keep the telescope in this position, and adjust the spirit level until the bubble is in the centre, which is done by means of adjusting screws. Then proceeding to the piquet G, keeping the level at the same height as the centre of the card M, and *bone* the middle of the card I, which if the visual ray cuts in the centre, it proves that the visual ray is parallel to the horizon, and consequently that the visual ray of the telescope attached to this level agrees with the spirit level.

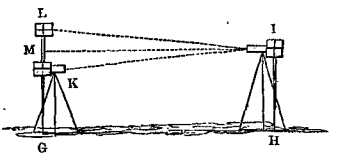


Fig. 916.

To rectify the Level by a single Station.—Having centred the telescope of the spirit level, place it on its stand; then knowing two points which are on a true level, and at a short distance apart, place the eye-piece of the telescope at the height of one of these points, so that the air bubble may be in the middle of the glass tube; then if on boning the second point it cuts the thread of the telescope, it is a proof that the level is properly rectified and fit for use.

It is known that the point A at the corner of the house B is on a true level with the cill of the window of the inn D at C: centre the telescope to that level in such a manner that the thread always cuts the same point when turned either way.

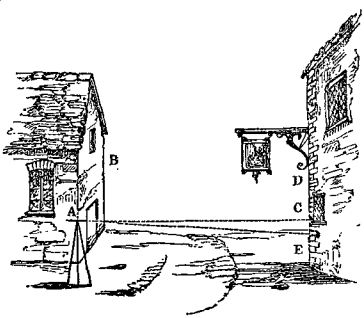


Fig. 917.

The Spirit Level in general use, of the most convenient and improved form, has a telescope *ab*, supported at each end, and a spirit level below it, inclosed in a brass tube, with a piece of glass let in at the upper side, to observe the position of the air bubble: the instrument has a compass usually attached to it. By means of the socket F, and the screw below, the telescope may be raised or lowered at pleasure; on the plate M are four levelling screws, which pass through the upper plate, and by which it may be adjusted. The cross hairs in the telescope are fixed to a brass ring placed within the tube, and are kept in their position by four small screws, as seen at *o o n*. The eye tube at *a* is to be drawn out until these hairs appear exactly in the focus of the glass, and are clearly seen. The telescope is then directed to some vertical object or piquet, and by turning the screw *g* it is raised or lowered to the required point. Clear and distinct vision of an object is obtained by turning the screw B, which by its connection with a rack and pinion contained in the tube which carries the object-glass, either lengthens or shortens it: when this has been done so that the horizontal hair is observed to be in contact with the object, turn the telescope half round, so that the spirit level is above, and see if the same point of contact is preserved; should it not be so, then the screw *o o* must be turned until it is right in both positions: the horizontal hair being adjusted, the vertical one must also be treated in the same manner; when both are properly adjusted, their intersection

appears in the centre of the telescope. The spirit level must then be adjusted in a manner that it shall be exactly parallel with the axis of the telescope, or what is called its line of *collimation*. The end of the level next the eye-glass has a screw by which it may be elevated or depressed at pleasure; having by means of this screw got the bubble in its right place, the telescope must be reversed again and again, until it is seen that the bubble steadily maintains its position. To take an observation, the three legs of the stand are opened and placed firmly on the ground, with the lower plate of the instrument as nearly level as the eye directs; then by turning the various screws the level can be soon brought into its proper position: three adjustments are always required for the Y spirit level: the first regards the wires of the telescope, which should be made to coincide very exactly with the axis of the rings on which the telescope turns; the second adjustment brings the level parallel to this axis; and the third sets the telescope perpendicular to the vertical axis, so that the level may preserve its position when the instrument is turned round upon the staves.

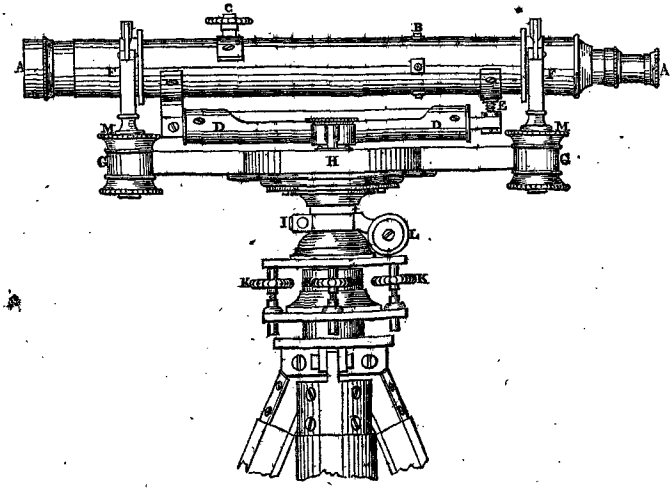


Fig. 918. SPIRIT LEVEL.

A A, the ends of the telescope.
C, screw for adjusting the telescope.
E, screws for elevating the instrument.
G, the frame.
I, screw to secure the instrument.
L, rack for side motion.
B, the screw.
D, the spirit level.
F, the Y's which support.
H, the compass.
K, screw to elevate the instrument.

To adjust the line of collimation, the eye-piece being drawn out, you should direct the telescope to some fixed object, care being taken that you get a distinct view of the cross wires, and that you notice where their intersection cuts: after this, by turning the telescope round on its axis, you must observe whether the wires cut the same object in the same place: should they do so, the instrument is fit for observation; but if this is not the case, the wires must be moved by turning the small screws near the eye-end of the telescope until half the quantity of error is got over, and then trials must be made again, till the adjustment is correct. To place the level parallel to the line of collimation, the telescope must be moved till it lies in the direction of two of the parallel plate screws, and by then moving the screws the air-bubble is brought to the middle of the glass tube: the telescope should then be reversed endwise, that is to say, one end brought in the place of the other, and then the air-bubble examined again; if it be not in its proper place, the parallel plate-screws must be used to make it: repeated trials are needed to effect this properly. To set the telescope in a perpendicular position with its vertical axis, it should be first placed over two of the parallel plate-screws; then by unscrewing one, and screwing up the other, the air-bubble may be brought to the centre of the tube; then the instrument must be turned half round, and if not correct, then again adjusted; then turn the telescope one quarter round, and by repeated trials its adjustment may be completed.

Troughton's improved Level is preferred by many to that of the Y, in consequence of its adjustments not being so likely, after they are once perfected, to derangement. The telescope rests at once upon a horizontal bar made to turn round upon the head of the staves which support it, in the same manner as in the theodolite. The spirit level is placed on the top of the telescope, and over it the compass-box: the wire plate has

three threads, two of which are vertical and the third horizontal; there is also sometimes a micrometer scale, fixed perpendicularly on the diaphragm in lieu of the wires: one edge of a fine slip of pearl with straight edges is applied for this purpose, which is divided into hundredth parts of an inch, and again subdivided into lesser quantities: in the fixing of this pearl micrometer the divided edge is placed so that it intersects the line of collimation, the central division indicating the point upon the staff where the level falls. The telescope generally shows the object inverted, consequently fewer glasses are required; and in this as in the Y level, the line of collimation and the level must be made parallel with each other, and the telescope brought into a position exactly perpendicular to the vertical axis, and so that the air-bubble when turned round horizontally should always preserve its position in the middle. This kind of spirit level being firmly fixed in its cell, the line of collimation has its adjustment given by the aid of two screws near the eye-end

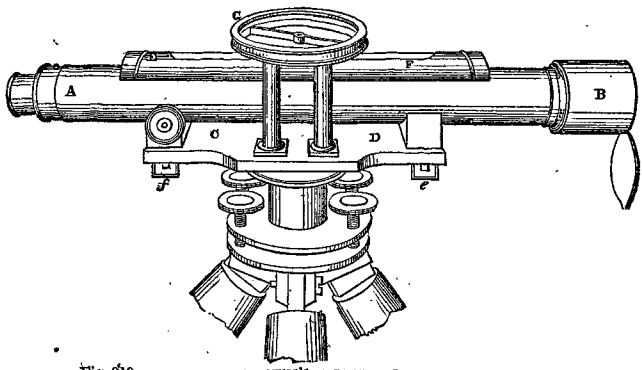


Fig. 919. TROUGHTON'S IMPROVED LEVEL.

A B, the telescope.
E F, the spirit level.
e f, capstan screws for adjusting the level.
C D, horizontal bar.
G, the compass-box.

of the telescope. A bench mark made against a wall should be every now and then examined by the instrument placed at the same height from the ground, and any error in its collimation then would be readily discovered.

Mr. Gravatt's Level is another modification of the above, and has an object glass of larger aperture and shorter focal length; it also has a diaphragm with cross wires, and the spirit level is placed above the telescope; there is also a small mirror so fixed on a hinge that the position of the air-bubble can be seen at all times by the observer; at the same time he reads off the staff.

Levels were formerly constructed with two telescopes, as A B and C D, each about 20 inches in length, placed in such a manner that when the eye-glass of A B was at A, that of C D was at D: each of these was so contrived that they could be elevated or depressed at pleasure, by screws placed at F and E. G I and H K were pivots placed at right angles with the bottom, and were the points on which the levels were supported: by turning the rule E F round on its pivots, the two telescopes were made to change their positions. To the support of the level I K is attached a weight at X, of a square form, and weighing 3 or 4 pounds, which is placed there to maintain the telescopes in a state of equilibrium, but so as not to prevent their motion on their axis at Q. At R is attached three rings which hold the eye or handle V: by means of the handle at T, which passes through the upper part of the box at S, the levels are raised or depressed when required; the box Z, which contains this spirit level, is made of mahogany, and is furnished with a screw at Y to adjust the level.

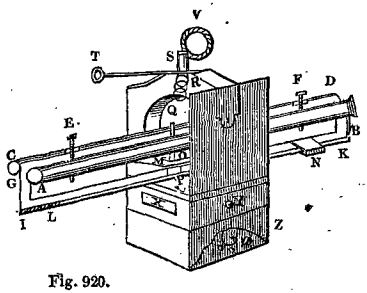


Fig. 920.

Such a box placed on its stand was much in use in France, and its rectification was effected in the ordinary way, by centring the two telescopes in such a manner as to make their visual rays always in a parallel with the pivots on which the circular motion of the telescope was made: the level being mounted on its stand at the same height as the object to be observed, the weight was permitted to remain at the bottom of the box, so that the telescopes were not subject to motion or to oscillate: then looking through the

eye-glass of the telescope A B, at any line parallel to the horizon, as that of the line *a b*, on the house C, so as to cover it exactly with the thread of the telescope; then turning the telescopes half round on the two pivots G, H, so that the telescope A B, which was on the left, comes on the right hand; then looking through the same telescope A B, if the thread still covers the horizontal line *a b*, it is a proof that the telescope A B is well centred, and that its visual rays are parallel to the two pivots G and H: should it either cut above or below, the screw at E must then be turned until the visual ray cuts half way between *e* and *f*; then turn the telescope round on the pivots, so that the telescope through which the observation has been made may pass from right to left; on looking through it, if the thread cuts the line *e f*, it is a proof it is well centred. The same rule must be observed with the other telescope, and both being properly centred, it is only then necessary to have the two visual rays parallel with the horizon, and this is done by putting the weight into equilibrium: after this is done, point the telescope towards the object, as the house C, and if in looking through the eye-glass of the telescope A B, its thread cuts the object in any point, as G, and having turned the whole level to make the eye-glass D of the telescope C D come to the same point, it is then a proof the visual rays are parallel with the horizon. The weight N, by being advanced or pushed back, changes at once the equilibrium of the level, and by the whole it may be truly and correctly adjusted.

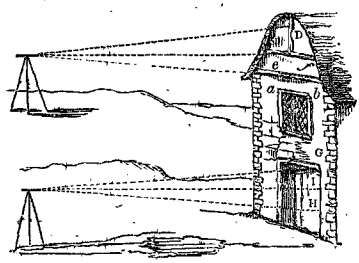


Fig. 921.

Level lines and points are all equidistant from the centre of the earth; the points B, K, L, and C, are equidistant from the centre of the globe A. There are two descriptions of levels, one called the true, the other the apparent: the true level is that which follows the circumference; the apparent is that which is drawn perpendicular to the radius of the circle: B G I F, which is so drawn at the end of A B, is the apparent level.

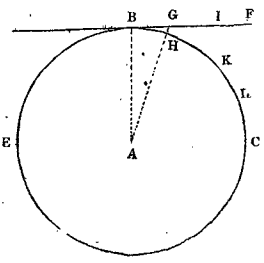


Fig. 922.

The term levelling implies the idea of bringing any thing to a level or flat; but, as engineers use it, it simply means the process by which the quantity of deviation from a true level is ascertained, the object being to find out if the surface be raised or sunk, or what is the slope or inclination. Level lines or level planes are supposed to be perfectly flat, or parallel with the horizon where they exist, and a sheet of water at rest may be supposed to have its surface level, for if any part of the plane on which it rested was lower than another, it would run in that direction.

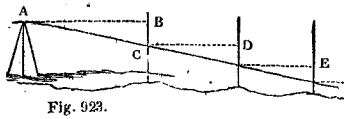


Fig. 923.

It therefore follows that some allowance should be made in levelling through very long distances, as from E to D, D to E, and B to A, and for this very accurate tables have been completed for all distances within the range of an observation.

We have also to make some allowances for the refraction, which varies from $\frac{1}{4}$ to $\frac{1}{24}$ of the angle subtended by the horizontal distance of objects. In the ordinary state of the atmosphere, the refraction is about a fourteenth of the horizontal angle, and the radius of the curvature of the ray seven times that of the earth. The effect of refraction may be allowed for by computing the correction for curvature, and then taking one-seventh for the quantity by which the object is rendered higher by the refraction than it ought to be.

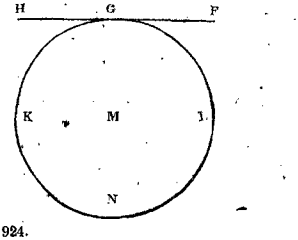


Fig. 924.

Numerous tables have been drawn up to enable the engineer to correct the curvature and refraction for distances in chains, feet, or miles; the corrections for refraction are taken usually from one-seventh up to a twelfth of the apparent above the true level, which is affected by the state of the atmosphere.

Suppose a spring to issue from the earth at G, the water would not flow along the line H F, which is the apparent level, but would flow towards K and L, in the circle N, and

thus it is apparent the true level is the earth's curvature: all bodies at an equal distance from its centre are supposed to be level.

In levelling for a Railroad or a Canal, it is often necessary to place the levelling staves 300 or 400 yards apart, and then it is important to make some allowance for the curvature of the earth, as we shall hereafter describe; but before we proceed, it is necessary to describe the staff or target made use of for determining the height of the several objects above or below the level line. The most common form is that of a rod 1½ inches square, and 6 feet 6 inches long, made of mahogany, and inlaid on its face with a white wood to receive the divisions and figures: the staff consists of two pieces dovetailed into each other throughout their whole length, so that one half of the rod slides upon the other, in consequence of which the rod can be pulled out or extended to 12 feet long, and yet will leave a foot of the two halves joined together for maintaining the straight line of the instrument: the divisions begin to count from the bottom of the staff.

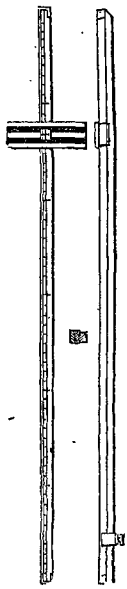


Fig. 925.

The vane is a thin piece of mahogany 10 inches long and 3 wide, having projections behind, which form a socket for fitting the rod, and enable it to slide up and down; this motion is rendered more certain by the addition of a flat spring placed in the socket. In the centre of the vane is pierced a hole, through which may be read off the figure on the staff, and the edges of this hole being chamfered, the horizontal wires which cross it can be distinctly perceived as they lie over the divisions of the scale beneath: when this staff is placed in a truly vertical position, its vane can be elevated or depressed, as the signal is given by the engineer who is at the levelling instrument; for the telescope cannot be altered by elevation or depression, therefore the vane is moved upon the staff until it is brought into exact coincidence with the horizontal hair of the instrument: so that when the cross-wire of the vane is raised so high as to intersect 6 feet, there is a stop to prevent its being pushed higher: when a greater height is required, the vane is put to this height, and then it is raised by sliding up the front portion of the staff, which carries the vane with it.

Several methods of marking these rods are adopted, but all begin to count from the bottom of the staff: some have a double scale of divisions running up the middle of the front; on some the side consists of feet and inches divided into tenths, and others of feet divided into hundredth parts, without regard to inches. When the levels can be taken in inches and tenths, or in feet and hundredths, the calculations are rendered more easy and simple, and it has been suggested that the decimal division should be adopted for rules and scales generally.

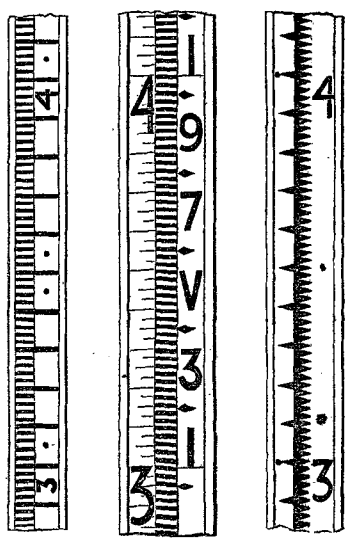


Fig. 926.

The staves now in use are generally without vanes, having their graduations distinctly marked in feet, tenths, and hundredths; these were introduced by Mr. William Gravatt, and are made of three pieces of mahogany with joints at the ends, to enable them to be united in one length of 17 feet or more; such staves can be packed up with the stand of the instrument, and are more portable. Mr. Sopwith of Newcastle has improved upon these, by adding a spring catch to that which slides, so that it is more easily retained in its place; but, however correctly these may be graduated, if the attendant who holds them is not very careful, errors of great magnitude may result, for when the face is turned from the last forward station to become the next back, an error of an eighth of an inch is sometimes the result of carelessly placing it on the ground: to remedy this the greatest attention should be observed, and the stave should be

pressed firmly into the ground at each station, and then on turning the face, there will not be much change apparent in the level taken.

When it is required to know whether the points E, E, are elevated or lower than the points C and G, place piquets at D, E, and having properly rectified the level, place it against the piquet at B C, and bone the line E through the telescope, and the card must be raised or lowered until the visual ray meets the centre of it at E; then measure the height that the centre of the eye-glass at C is above the base B, and set off from the base of the piquet D this same height B C, and the height then up to the point at E on the card, will be the difference of the levels.

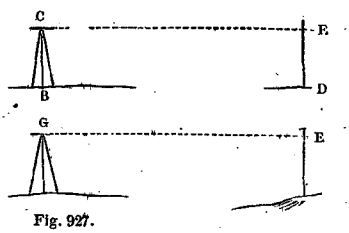


Fig. 927.

If the observed height fall lower than the sight point, as at K, it proves that the ground is lower than at I, as much as the difference is between K and H.

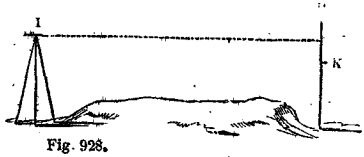


Fig. 928.

When it is required to find the difference between the levels of the spring at A and another at B, piquets of the required length must be fixed at the stations D, C, and B, and the level may be placed at C; then by taking the necessary observations, measuring off the heights on the piquets, and deducting the height of the stand, it may be easily computed; or, suppose the height from B to F to be 16 feet, and that of A D 10 feet, the difference will be the variation in the level.

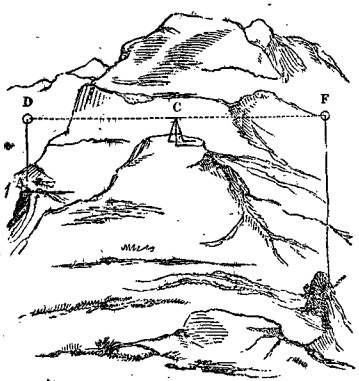


Fig. 929.

If it be required to ascertain whether a well at the station at F is above or below the level at B; after rectifying the level, place it at D, where both piquets can be seen: when the observations have been made on the piquets, their difference can easily be calculated, which will be the variation in the level.

If it be necessary to plant piquets in a line from the trunk of the tree A to the descent at B, where hills as F, G, and H, intervene; a piquet must be placed at A D, and another at B E, and then the level must be stationed between the two objects A B, at any place where the piquet A D can be seen.

From the station F, bone the piquet A D, and then looking through the other end of the level place in a line the piquets Q, R, S; and if this be found not to cut the piquet B, then from the last of these piquets bone R and Q, and take up another station, as at G, boning through the piquets P, O, N; we must continue our observations until by boning from the piquets A D and B E, we find B E in the visual ray with the other piquets; then a line drawn through the foot of the piquets planted on the hills and valleys between the two stations A and B, as A, N, O, P, and B, will mark the shortest road required.

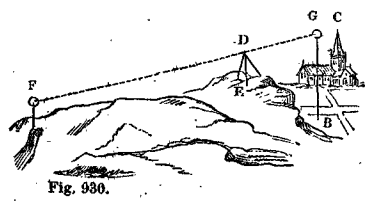


Fig. 930.

When the district through which the levels are to be taken is much intercepted by trees or buildings, it is often found very useful to leave at convenient intervals marks which may be cut in posts, stumps of trees, or painted on a fence or building: such a bench-mark will be valuable for future reference, and during the survey to check the levels made in different directions; and it should always be established at the end of every day's labour.

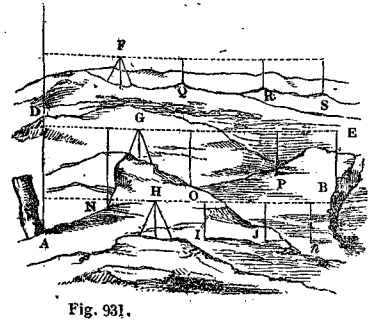


Fig. 931.

If it be required to ascertain whether there is any fall from the point A to the little hillock at G, piquets may be placed first at A and K, and the level F, having made the necessary observations at the station E, may be removed to I, where the piquets H and D can be observed; then by a simple calculation the difference in the levels may be found.

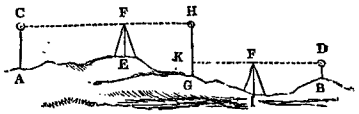


Fig. 932.

The difference between the levels of two houses E and O may also be found by planting piquets at G and L, and the level at D, H, and C: so may the inequalities of a country,

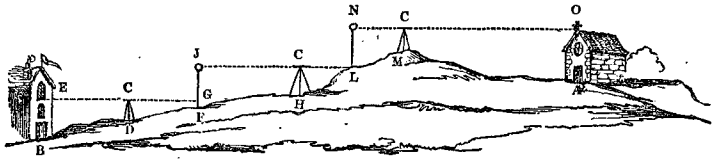


Fig. 933.

as from A to C, be marked, and a canal set out upon a dead level, K, O, P, being piquets, and L H T the position of the level used for making the observations: M and Q show the depth of cutting.

In this latter example D, F, H, and T show the position of the level for taking the observations, and K A, O N, P R the station of the piquet.

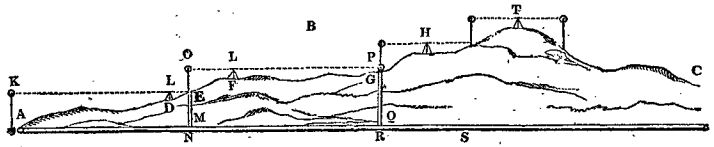


Fig. 934.

The ordinary method of levelling the foundations of a building, or an area of moderate extent, for the purpose of forming a drain or watercourse, is by a level 10 or 12 feet in length, formed of wood, and having attached at A a string which holds a plummet that falls into a hole below; this simple instrument is blocked up until it is brought perfectly level; then the difference in the heights of the blocks is taken, which added together constitutes the variety in the level.

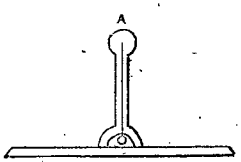


Fig. 935.

The level shown at B has an upright straight edge, which when placed against a wall or building at once indicates, by the play of the plummet, how much in that length it is out of the perpendicular.

These implements all depend upon the circumstances of a level line being a tangent to the earth's curvature and of a plumb line disposing itself into the direction of a radius of the earth, of course perpendicular to the middle of that tangent, and that the level direction is a right line. To prove the correctness of such an instrument it should be placed upon a surface known or ascertained to be perfectly level, and such may always be formed by wedging up a plank at one end or the other: after finding that the plummet hangs in its proper vertical direction, it should be reversed by turning the two ends of the level in an opposite direction or position, when, if the plummet retains the same place over the line, the instrument may be depended upon.

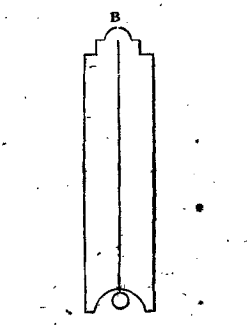


Fig. 936.

C and E are other varieties of levels which are in use for ascertaining how much a stone or other body may be out of a level; the plummet in the one falls over a mark on the cross piece towards D, when it is perfectly level at the feet, and in the other over a graduated arc of a circle.

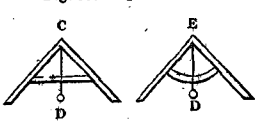


Fig. 937.

Small spirit levels are also used, which are made of glass, and mounted on brass tubes; M and V are small brass plates which have an upright and horizontal cut made through them, so that the eye can see from one to the other, and when the bottom O K P is placed upon any surface, by looking through M N a level may be obtained: sometimes a glass tube F is placed on the top of a box H, which is furnished with an eye-hole at O.

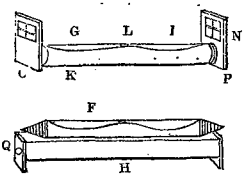


Fig. 938.

The earth's diameter being nearly 41,796,480 feet, or 7916 miles, it has been estimated that the height of the apparent above the true level for every mile is a little more than 8 inches. To find the difference between the true and apparent level, the distance levelled should be squared, and its product then divided by the mean diameter of the earth, when its quotient will be the difference required: for the differences of the heights of the apparent levels at different distances are as the squares of those distances; in short lengths the differences are small, but they increase rapidly as the distances increase: in ten chains it is ·12 of an inch; in twenty chains ·5; in thirty 1·12; in forty 2; in fifty 3·12; and in 100, 12·50 inches.

Compound Levelling is usually adopted where great accuracy is required, and this is performed by taking back and forward sights; by this means errors are easily corrected: the height obtained at a back or forward observation is deducted from the other, so that when these heights are compared together, the result may be depended upon, it being obtained upon the spot; sufficient correctness is arrived at: in setting out a canal or railroad, it is usual to go over the same ground a second time in an opposite direction, beginning the first operation where the latter ended; and if the results turn out the same in both cases the correctness is sufficiently ascertained. It is, however, necessary to measure and set off the distances with the chain, and to reduce all the sloping measures to their horizontal value: the distance between the sights ought to be short, and the piquet-bearer should be careful to hold his staff upright, and to place it on the same spot for a forward or back observation.

Drawing a Section or Profile of a Country after it has been levelled, to enable an estimate of the expense to be made, for the construction of a canal, railroad, or other work, is the next point to be considered. This drawing, to be useful, should be on a large scale, that is to say, from 8 to 16 inches to a mile: in the first instance an inch represents a furlong, and each chain the tenth of an inch; when this scale is doubled, it is usually called 5 chains to an inch. A straight line representing the base or level is first drawn, which may represent the horizon; on this is set out the several distances that have been measured upon the ground; the profile lines are then laid down, and after the heights are accurately set out, the surface of the country may be traced through them: by such a section a sufficient knowledge of the expense may be acquired for the formation of any engineering work that may be constructed.

In the year 1742 it was proposed to the Academy of Sciences at Paris, to show on all maps by the means of contour lines the respective levels of the districts surveyed. The idea seems to have been suggested by the marks left around a hill after the waters on an inundation had been drawn off; supposing the valleys around a number of hills were to be inundated, and the water suffered for a sufficient length of time to stand at one level, then if piquets or stumps were driven around the margin, to mark the extent of the surface of the water, and their position mapped and a line traced through them, then such a contour line would show the various spots which were at the same level, and if it were possible to lower the surface by degrees, and draw off a foot of its depth at each time, and mark its various boundaries in a similar manner and map them as before, such a series of contour lines would accurately express the height of the ground, and show where the relative levels were to be found: we can imagine Shooter's Hill, which is 400 feet in height, immersed in water, and that it could be lowered or drawn off a yard in depth each time; then if stumps could be driven to mark the water's edge, as this was done, and these stumps or the figure they comprised mapped, we should then have expressed by contour lines the extent of the level planes at every yard of elevation.

In public surveys where three chains are used to an inch, such a series of lines laid down would be found of the greatest possible service to the engineer about to cut a road or canal through the country so mapped, as he would at once see all the points which were upon the same level: for the supply of a town with water such a survey would be of the greatest importance, and facilitate the operations of the engineer.

The engineer, when surveying a country through which a railroad or canal is to pass, must not only pay the greatest attention to the levels of the several districts, but also notice the manner in which the earth's strata are disposed; if he has an eye to judge accurately, he may, like Brindley, perform much of his task by walking over the intended line, and get a thorough knowledge of the difficulties he has to overcome: general ideas are too frequently

thrown aside, and the entire attention devoted to minutiæ: in taking the levels of a valley through which a stream discharges itself into the sea, and where there are many mill weirs, and their fall can be ascertained, it will be of considerable service previously to decide the level of the river's mouth, its entrance into the sea, and also the slope of its bed, which may be calculated by adding the several falls together, and taking an average inclination per mile of the stream: although this is not a very accurate way of proceeding, it will serve as a check to gross errors.

Inland districts are not necessarily higher than the level of the ocean, and in the fens of Lincolnshire and elsewhere, the slope of the streams is so inconsiderable as to be hardly perceptible, the fall being frequently less than 2 inches to the mile; the Thames from Lechdale to London bridge is 146½ miles, and in this distance the rise from low-water mark is 248 feet, consequently its fall averages about 20 inches per mile, though for a part of its course the slope of the bed is not more than a foot. Surveys made through a country where the falls of the rivers are known may be frequently rendered more accurate by comparing the levels as taken with the instrument with those observed in the manner alluded to.

Trigonometry teaches the method of measuring all kinds of distances as well as heights by triangles; it enables the engineer to ascertain how many feet or yards there are in a right line from one place to another; to measure the breadth of a river; the length of a line of fortification; the opening of a breach; the distance of a fort even when water intervenes, or the surrounding country is inaccessible: it also enables him to measure the heights of hills, mountains, and buildings of every kind with great precision: formerly these two branches of trigonometry were called *longimetry* and *altimetry*.

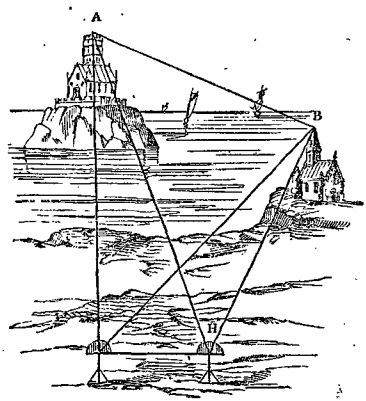


Fig. 939.

By the first was understood the method of measuring in a right line from one place to another, as to find the width of a river, or the distance of one building from another, as the distance of the castle A from the church B: it is evident from the stations at G and H, two angles may be measured; that by computation afterwards the distance may be known accurately.

By the second the height of the tower at C from the point D may be found from the station points where the instrument is placed.

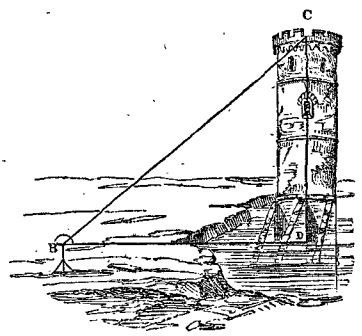


Fig. 940.

For suppose the circumference of a circle divided into 360 equal parts or degrees, these each into minutes, and these into seconds, it will be easy to measure the angle taken by the demicircle with the points C and D; its magnitude may be expressed by degrees, minutes, and seconds; this division of the circle, called usually the sexagesimal, was that adopted by the ancients. Supposing the point occupied by the demicircle to be marked by the letter B, the ratio that C D bears to C B is called the sine of the angle, and the ratio of B D to B C the cosine of the angle, or, as they are usually written,

$$\frac{DC}{BC} = \text{sin. A}\,; \quad \frac{BD}{BC} = \text{cos. A.}$$

The ratio which the sine of an angle bears to the cosine is called the tangent of the angle; the inverse of the ratio the cotangent; the ratio of unity to the cosine of an angle the secant, and that of unity to the sine the cosecant. The difference between unity and the cosine is termed the versed sine, and the difference between unity and the sine of an angle the coversed sine.

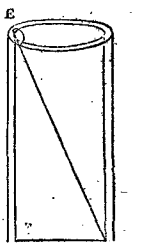


Fig. 941.

The depth of all places may also be found, as the depth and width of all ditches and cavities, as that of E F, and the breadth at the bottom.

The demicircle is placed at E, and the angle that the bottom of the well or surface of the water makes with the perpendicular line E F is accurately measured; then by means of a scale or trigonometrical calculation, when the diameter is ascertained, its depth can be readily found; or, if the angle be taken, and the depth ascertained by measurement, the width at bottom may be found. Whenever it is required to measure a distance or space that is not accessible, care must be taken not to make the angle more acute than absolutely necessary, and the same rule must be observed in planting over piquets to measure angles between other objects: in all instances we must endeavour to obtain them as large as possible.

By means of the triangle A C B we can ascertain the distance from A to B, and by the triangle D F E that from the windmill to the church.

The exact situation of these points may always be determined by means of the triangle; but we cannot by instruments measure them exactly: to resolve its value by construction, it is only necessary to establish the data of the things given, and then measure the lines and angles that are unknown; if the data be sufficient this representation on paper affords us

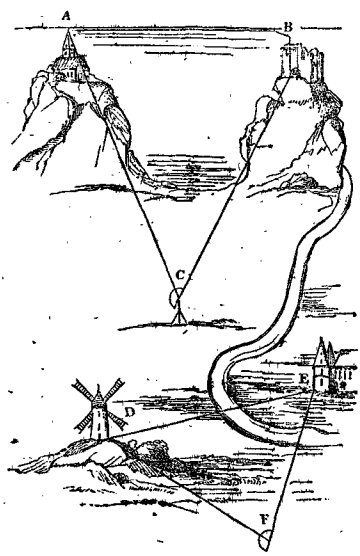


Fig. 942.

the means of finding the lines and angles that are not given, and when these unknown quantities are drawn out proportionate to a scale of the known, it is only requisite to measure them by the same scale to ascertain their values. Suppose it is required that the distance between the inaccessible points A, B, should be known, as we can take up a station at C, and measure the distance from C to A and from C to B, the three terms of the triangle A B C, viz. the length of two sides and the angle comprised can be found. The distance from the windmill, D, to the church, E, may be also calculated when the angle from F is known, together with the length, F D and F E.

The knowledge of the three angles is not enough to enable us to obtain the length of each side, as there may be many triangles like L M V and G H I equal to each other, and the length of their sides different: we must, therefore, always be enabled to measure a base line; as when the distance from one place to another is required, we must place our piquets in such positions with regard to our instruments that the angles made are not too acute or too obtuse.

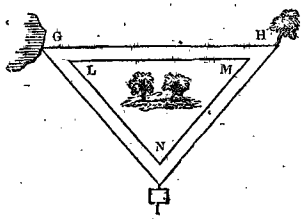


Fig. 943.

Trigonometry being based on the knowledge of sides and angles, it is necessary to be very exact in our observations, as well as in the measurement of the line from which we calculate our angles, for if the ground-work be insecure, the building up will be in jeopardy.

To find the distance between one place and another without actually measuring it may be done when it is allowed to approach them, as from the point F to that at G: a piquet planted at I was found to be by measurement 50 yards from F; the same distance was set out in a straight line towards K, where another piquet was planted. The distance from G to I was then measured, which was found to be 60 yards, and this distance was set out towards L, and a piquet planted: then

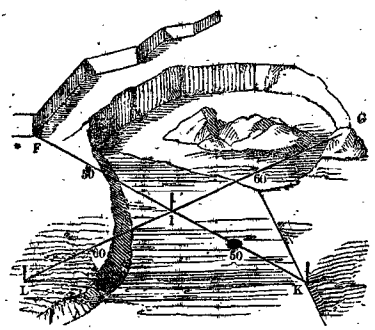


Fig. 944.

the distance from L to K was measured, which was found to be 102 yards, the exact distance from F to G, afterwards measured with a cord.

To measure the Distance between two Objects inaccessible from one to the other, but accessible from a station, as the distance from the tower A to the tree B, supposing it to be possible to place a piquet at C, whence we can proceed to the two objects A and B. Measure in a right line from A to the piquet C how many feet it is, as 70: then measure in a right line on A C prolonged to D 70 feet, so that A C D may be 140 feet. Then from the point B measure B C, in a right line, and call it 100 feet; measure the same distance on B C prolonged; then measure the distance E D, 150 feet, and which is that of the inaccessible length or distance A B.

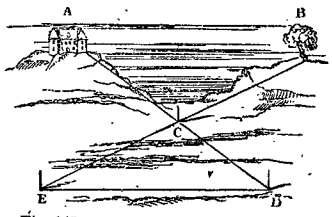


Fig. 945.

By means of a Piquet to measure the Distance from one Object to another, when it is only possible to approach one of them, as to measure the opening or bar of a river. — Plant at the point A a perpendicular piquet, 4 or 5 feet high, as at A C; place on the summit C, the blade of a knife with its back turned to the piquet; elevate or depress this blade until you see, looking along the back of it, the point B: then keeping the knife at the same opening, turn round to the land side, opposite a level piece of ground; replace the knife in the piquet C, and its back against this piquet, in order to look along the back of the blade until the visual ray cuts the ground, as at D: the distance A D will be that of the bar or entrance of the river A B.

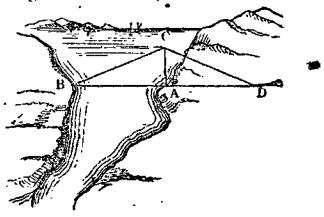


Fig. 946.

An observation similarly made at E G, and tried along the ground from H to I, where the base may be measured, gives the width of the river.

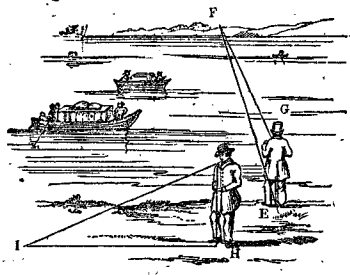


Fig. 947.

By means of piquets, the length of the ridge of a roof may be found, as that of the church at N O. Piquets placed at P R on the line *a b*, drawn on the ground parallel to the ridge having on their tops two laths arranged like a cross: these must be moved along the line till they are perceived to be opposite the points N, O, and then the distance P P being measured, the length of the ridge will be similar.

To enable the observer to be more accurate, the piquets placed at P and R on the base line *a* may be mounted with cross staves, the arms S T and Y X being in a line, and Y Z and Z 2 at right angles with it: should the distance of the objects be considerable, the observations so made would be far from accurate; when within a few feet or yards, the dimension measured on the ground between the feet of the piquets might be sufficiently near the truth for ordinary purposes. This practice somewhat corresponds to the common method of *boning*, or booming as it is sometimes termed, which often leads to very erroneous calculations. In Holland, wherever difficulties are offered to the navigation of a channel by the overflowing of the coast, and the course not distinctly known, poles are set up to enable the sailors to steer in a straight direction, from whence probably we have the term; and in this manner lines are set out with booms or spars when a canal is to be cut; but without great care it is scarcely practicable to make a very long line straight by such means.

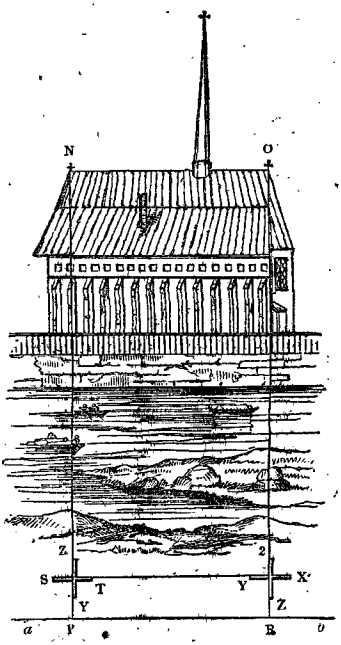


Fig. 948.

By means of Piquets to measure the Distance between inaccessible Places, as that from the tower A to the windmill D. Trace on the ground, where you are to perform the operation, a line parallel to the given length to be measured, as the line S V; then attach two rules at right angles, placed in the form of a cross, on the heads of the two piquets, each 4 or 5 feet in height. Place these two piquets at any points on the line S V, and look along them in such a manner as to discover the objects as well as the piquets, as at C; by the rule I K you may see the tower A, and by the rule E F the piquet D. Then from the piquet D, observe by the rule L M the mill B, and by the rule H G the piquet C, which may be done by bringing these two piquets nearer together or further apart, always keeping them in the line S V, until you can discover the objects before named, which happens when at the points C and D: then the length C D will be equal to the inaccessible length, A B, between the tower A and mill B.

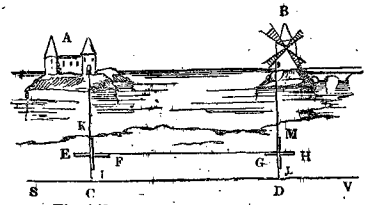


Fig. 949.

To find the Height of an Object, A B, when it can be approached.—Place a mirror at C horizontally at any place on the ground, with its back downwards, so that the glass may be uppermost; retire from the mirror at a distance precisely equal to the height of the eye from the ground, as at D, and standing perfectly upright, observe if the top of the proposed height can be seen in the middle of the mirror; if not, see if the mirror be too near or too far from the object, and place it either nearer or farther from it. When the view of the object in the mirror has been obtained, measure on the ground the distance from the centre of the mirror to the foot of the proposed height, as from C to A, and it will be the height required.

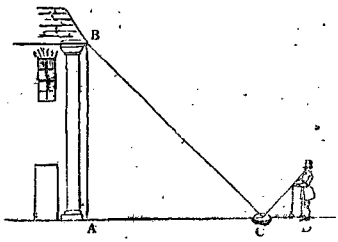


Fig. 950.

To measure by means of two Piquets Heights to which the Foot is accessible.—Take two piquets, as E, C, one of which is half the length of the other; elevate them perpendicularly in the ground, on a level with the foot or base of the height which is required to be ascertained, and so that the shorter piquet may be its own length distant from the longer one; look along their tops, and walk either backwards or forwards, keeping them the same distance apart, until by the same visual ray the summit of the object to be measured can be seen. The distance from the foot of the object to the foot of the short piquet, viz. from C to A, added to its length, gives the height of the object.

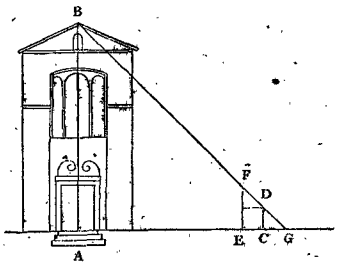


Fig. 951.

To measure a Height, when the Base is accessible by means of a Piquet.—Retire from the foot of the height to be measured as much as the height is supposed to be; plant a piquet upright on the ground, as at D E, on the same level as the foot of height, and as high as the eye; lie down on the ground with the feet against the piquet, and look along its top until in the same visual ray the summit of the height to be ascertained is seen. The distance from the foot of the height, A to C, to the place where the eye was when lying on the ground, will be the required height.

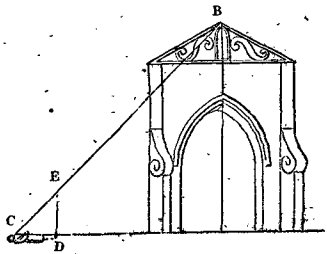


Fig. 952

Examples might be multiplied of measuring heights by means of the piquet, and it is mentioned in several ancient writers. We may imagine that Archimedes and Apollonius, who enriched geometry with so many new theorems, made use of the staff or piquet for several purposes, particularly where the properties of similar angles were to be exhibited: seventeen centuries have passed since these great men taught in the academies: the principles they have left us have been but little added to, although they have been varied in their application. Wherever the piquet is employed, its perpendicular position should be

regarded, and maintained, as the slightest inclination would affect the truth of the observations made with it.

To measure by means of a Piquet and the Rule of Three a Height of which the Foot is accessible.—Place on the ground at some distance a piquet C E, of any length; then retire from this piquet till, by lowering the eye to the ground, as at D, the top of the piquet and the summit of the height, B, to be measured, is seen in the same visual ray.

State the question by placing in the first term the distance from the point where the eye was placed when on the ground from the piquet; in the second term, the distance from the same point to the base of the required height, and for the third term, the height of the upright piquet: the quotient will be the required height.

From D C we will suppose 5 feet, and from D to A 25 feet, and the height of the piquet, C E, 6 feet: then we shall have

5 : 25 : : 6 : 30 feet for the height of A B.

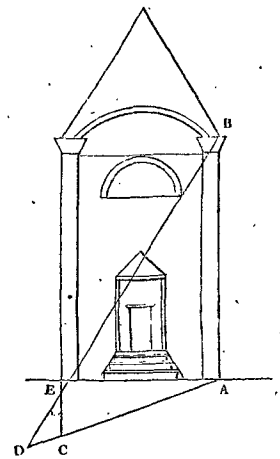


Fig 953.

For if a line be drawn in a triangle parallel to one of its sides, it will cut the two other sides proportionally; and the line which bisects any angle of a triangle divides the opposite sides into two segments which are proportional to two other adjacent sides: let the angle D E A of the triangle D A E be bisected by the line C E, making the two angles at E so bisected equal: then the segment D C will be to the segment C A, as the side D E is to the side E A, or D C will be to C A, as D E is to E A, and the line E C being drawn perpendicular or parallel to B A, cuts the two other sides proportionally, making D C to C A, as is D E to E B, or to its equal E A.

When the sun shines, if we set up vertically a staff of any known length, and measure the length of its shadow upon a horizontal or other plane, and measure also the length of the shadow of the object whose height is required, we may, by a similar rule, obtain it: as the length of the shadow of the staff is to the length of the staff itself, so is the length of the shadow of the object to the object's height.

To draw the Map of a Country à la Cavaliere.—We must be placed on an eminence which gives an opportunity of seeing the country to be mapped, and have some attendant acquainted with the names of all the places and objects before and around, as well as their distances from each other, that their relative positions may be set down. To transfer this rough map, or to draw it out fair, we must begin by drawing a line from the top to the bottom, and on this form a scale divided into as many miles as there are between the most distant places; then mark the site of the different places which come on this line, by taking in the compasses the distance right or left from the first position, performing the same operation with all the others: rivers may then be traced, as well as the various objects between them.

It would be advisable in mapping a country always to work upon a meridian line, and before any survey is commenced, its direction should be accurately laid down: where a number of parishes are surveyed, it is important that general instructions should be implicitly followed, that the whole when brought together may be examined: for example, all writing and figuring should be placed in the same direction; the top of the paper on which the representation is made should be considered north, and whatever the form of the plan, this rule should never be departed from: upon a sketch so made, a series of triangles may be extended at any time, and the respective sides calculated with precision. From an eminence or lofty site numerous towns and villages may be seen, and after the meridian line is established, their bearings from each other may be noticed upon the divisions of a card, which if drawn within a circle will serve to make the sketch. From a table showing the distance in miles of one place from another, this may be rectified and brought to approach the truth: or a circle may be traced on the ground, and after dividing it into 360 degrees, piquets may be set upon that part of its circumference which is in a line with the object, and the observer being stationed in the centre of the figure, the divisions of the circle may be noticed, and thus the sketch of a country may be made where instruments cannot readily be obtained, or a hasty survey is to be laid down.

If an estate could be seen at once, and its meridian line be determined, there would be no difficulty in mapping it, and approximating its area, by walking across it in the longest direction, afterwards triangulating it from this line as a base, and then uniting it with the

meridian line already drawn. Either the time or the steps taken may be counted from one position or station to another; the writer found Sir William Gill's Itinerary of Greece a sure guide, although it contained only the bearings of the places, and the time occupied in riding or walking; when the traveller has no better map, he must find his course by such general directions, which have often proved his only security.

Of Demicircles and their Construction. — They are usually made either of copper or of wood, and are 12 inches in length, 8 inches wide, and $\frac{1}{8}$ an inch in thickness; usually a sheet of white paper is glued on their surface, upon which the divisions are marked. To graduate the demicircle, divide its diameter A B into two equal parts in the point C; from this point, with the radius C A, describe the semicircle A D B, and from the point C elevate the perpendicular C I on the diameter A B, which will cut the demicircle A D B in two equal parts in D.

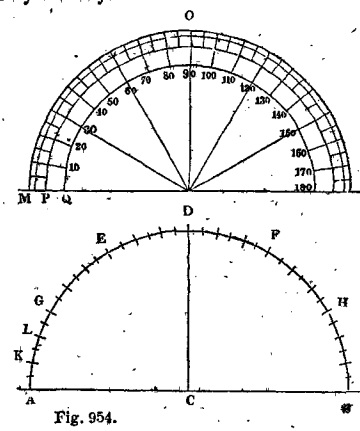


Fig. 954.

To graduate the semicircle A D B, open the compasses to the extent of the radius C A, and carry the opening three times on the semicircle A D B, viz. from A to E, from E to F, and from F to B; also carry the same extent A C, on the semicircle, from D to G and H: then the summit A D B will be divided into six equal parts. To have the ten degrees, divide each of these six parts into three other equal parts, as A G is divided in the points K, L, and G, and each of these must again be divided, and so on till the whole is divided into 180 degrees.

Demicircles with sights (*à pinnules*) used for measuring angles, distances, &c., are usually about 15 inches in diameter; the degrees are numbered from each extremity of their diameter, where a sight is attached by a screw, as at C and D. At the centre E is a movable rule with a sight at each of its extremities; in the middle of the semicircle is a compass to show the cardinal points.

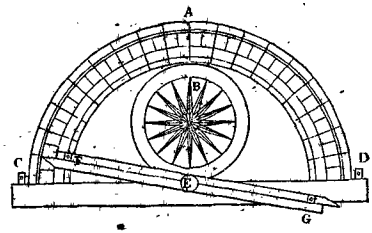


Fig. 955.

A telescope is frequently added to them, by which the angles of objects at a considerable distance may be very accurately taken, and the whole is placed on a stand: with such an instrument it is possible to determine the position of the several headlands and principal objects on a coast, to complete a maritime survey, and afterwards to lay them accurately down upon paper. Suppose two boats are anchored at a known distance from each other, and the bearings of the several objects taken from each; then if the measured distance between the boats be drawn out to serve as a scale, and the various lines laid down according to the observed angles, their points of intersection would denote the positions of the objects that have been noticed; or the same might be done on land, by selecting a plain on which a base line could be measured, and then fixing station staves at the extremities; from these station staves the angles which the prominent features of the country make with each other may be taken, and the whole may be laid down to any scale, by adopting a similar process to that previously described.

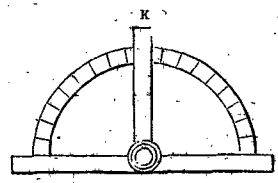


Fig. 956.

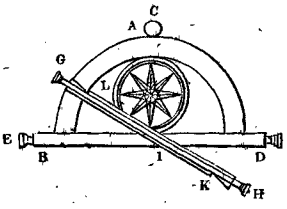


Fig. 957.

The instrument called the *station pointer* does not materially differ from a demicircle, over the centre of which moves a number of arms that can be directed to any object; generally three rulers, connected by a common centre, are so arranged that they can be turned

so as to open and form at one time two angles of any given inclination; the middle ruler, which is double, has a fine wire or thread stretched in the opening, the others have one similarly placed from end to end, so adjusted that the three tend to the centre of the instrument: they can readily be directed towards an object, and their angles accurately measured: such a station pointer may be made by graduating an arc of a circle on a sheet of glass ground on one side, upon which, with a pencil, all the angles may be marked; this, laid upon paper, may be easily set off and traced.

When the demicircle is to be used, it has its plane placed horizontally for taking distances, and upright for heights; having a joint which works upon a movable socket, it can be easily adjusted; a plumb line at once indicates whether it is truly vertical or horizontal.

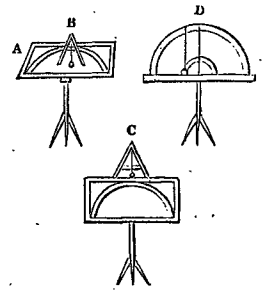


Fig. 958.

To take an angle with this instrument, we turn it in such a manner that the object A is seen through the sights on its diameter, and then, without moving the demicircle, we look along the alhidade or movable rule, and when through its sights the object C is seen, the angle A B C can be laid down. The number of degrees contained in this angle may be counted off between H and I, which may then be written down.

The demicircle now yields to the *azimuth instrument*, which measures angles with greater facility, whether vertical or horizontal, serving also the purposes of the theodolite; it does not possess the power of repetition, but should an error occur, it may be reduced or rectified by measuring the same angle upon different parts of the arc, which may be accomplished by turning the instrument on its stand, and adjusting it as required: such observations frequently repeated, and a mean result taken, are free from any great error.

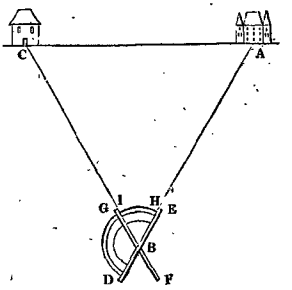


Fig. 959.

To take the height of an object the demicircle is turned or placed upright, and adjusted by the plumb passing through its centre, when its base will be horizontal and at right angles with the height to be taken. The alhidade is then turned until through its sights the object O is seen; the angle M N O will be ascertained, and the degrees may be counted off.

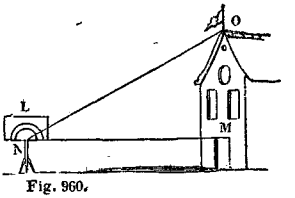


Fig. 960.

Distances between places inaccessible may be ascertained and measured in the following manner: when the angle A B C is taken, measure on the ground the distance between B A and B C, and construct upon paper with a scale the angle taken, and proceed as has been before described.

It will appear evident that if upon the angle G E F, the dimensions are set off from E to F and E to G that have been previously taken from B to A and from B to C, by the scale the distance between the objects may be accurately measured. We may infer that this instrument was used first by the Arabians, from the index or ruler which carried the sights being called an alidade or alhidade, which, on the limb of the instrument, showed the number of degrees or minutes that the object was above the horizon.

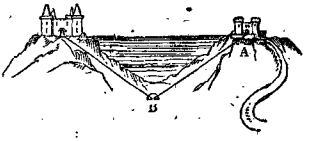


Fig. 961.

Besides the altitude and azimuth circle, we have now *mural* and *reflecting* circles for measuring the altitudes and azimuths of stars: the *mural* is so called because it is supported by a long axis passing into a wall, to which the plane of the circle is parallel; the *reflecting* circle carries a mirror, by which an object is seen by reflected vision; another object is viewed directly the two are brought to coincide, and the angular distance between them is measured by the inclination of the mirror to the axis of the telescope;

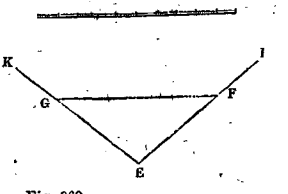


Fig. 962.

the repeating or multiplying circle is so contrived, that the observation made may be repeated or multiplied by reading it off successively on different parts of the graduated limb: the number of values thus found afford a mean result.

Distances between places where one only is accessible may also be found. Place the demicircle at the foot of the tower A, and measure the angle C A B; then place the instrument at C, and measure the angle A C B; by setting out these angles on paper, the distance between A and B may be found by a scale of parts, or by calculation.

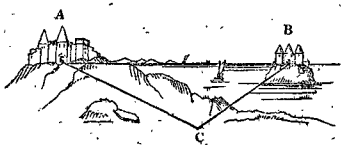


Fig. 963.

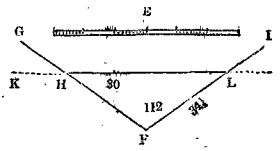


Fig. 964.

To ascertain the distance from the piquet at M to the angle of the building at N; place the demicircle at P, and measure the angle M P N; then draw the line R S, of the length or distance that P is from M, and construct from the point R a similar angle to that observed from P. Suppose it has been found by measurement that the angle taken at P was 112°, the length of the line P M was 83 feet, and the angle P M N 30°; if all these are accurately drawn out by a scale, the distance may be easily ascertained. R to T being the same as the measured distance from P to M, and R to I that of P to N, it is evident that by the scale the distance from T to I on the line X may be taken off.

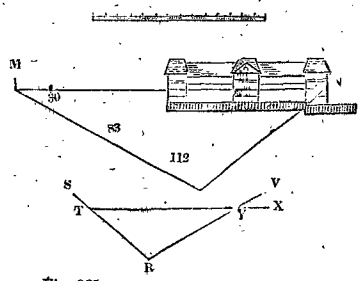


Fig. 965.

Distances between places inaccessible on all sides, as between A and B, may be found by placing the demicircle on a point C, where both objects may be seen, as well as a piquet at D. The demicircle is then turned in such a manner that the piquet D is visible through the sights of the diameter, and the steeple B through the sights of the alhidade. The degrees contained between the diameter and the alhidade must then be read off; keep the diameter in the same line C D, and move the alhidade until through its sights the tower A is seen; then read off again the degrees contained between it and the base line; remove now the demicircle to the piquet D, and measure this distance from the new station; repeat the operation, and lay the angles so taken down upon paper with a proper scale, as K F I M H N, and the distance between A B may be truly ascertained.

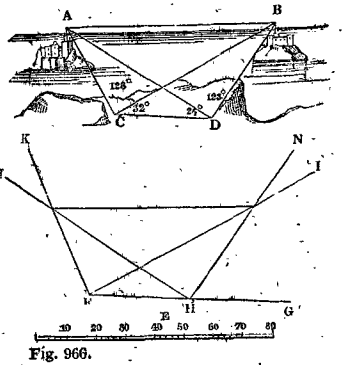


Fig. 966.

If it were required to ascertain how many yards distance it was between the points M, L, of a fortified town, by placing a piquet at N, and then measuring the angle, and the distance from N to L, and from N to M, the same might be laid down accurately on paper by

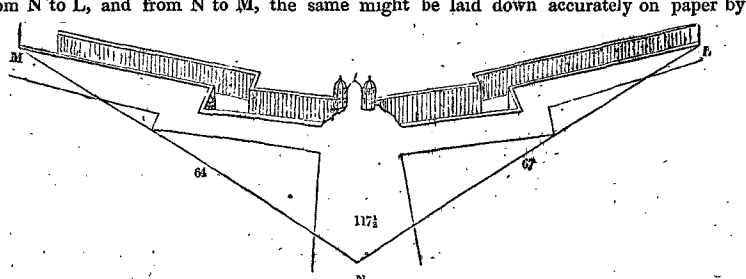


Fig. 967.

means of a scale: the opening of the angle, 117½ degrees, could be set out at Q, and the distanee O S made 67 yards, and O V on the line T 64; then by the scale P the distance from V to S will be found 112 yards, which will be that also from M to L.

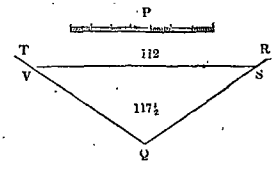


Fig. 968.

To find the length of a building, as from T to L, select two stations, as Y and P, and plant two piquets: at the first take the angle P Y L, which will be found to be one of 30°, and measure the distance between the two piquets, which is here 45 yards: then from the piquet P, construct the triangle Y P L, which is also one of 30°.

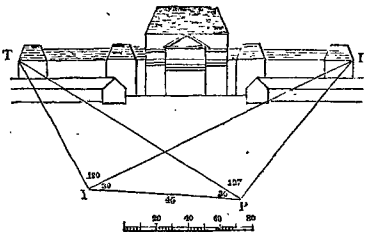


Fig. 969.

Then set out a scale, and draw *b d* equal to Y P, and the angles *b d g*, answering to Y P L, and *k b h* equal to L Y T; the whole may then be measured, and in this case the distance from *i* to *h* will be found 102 yards, which is the length of the building T L.

Maps may be laid down by means of the demicircle, and all the towns at A, B, C, D, E, F, G, H, be accurately measured, and put at their proper distances from each other. First place the instrument at H, and a piquet at N; after having taken all the angles, move the instrument to N, and make a similar observation: measure the distance from H to N, which here is 200 yards, and then lay down the several angles as observed accurately upon paper, and the lines at their intersection will give the positions of the towns.

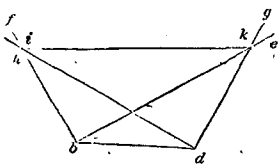


Fig. 970.

This system was practised in France as early as the seventeenth century, when a base line was measured from the town stationed at N and L, and all the others shown on the map accurately laid down from drawing a series of angles taken at the two stations.

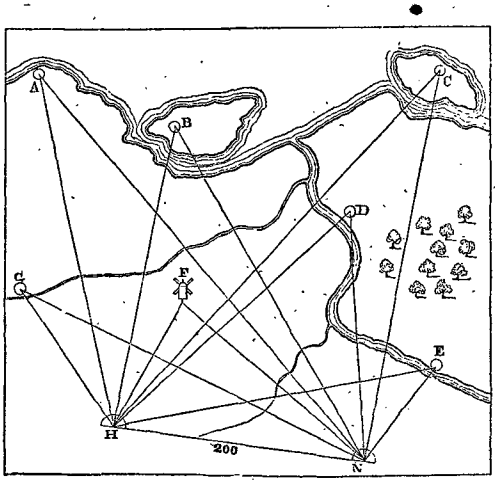


Fig. 971.

Picard, in 1670, called the attention of the moderns to the measurement of a degree of the meridian, and his observations were confined to a line stretching between the parallels of Malvoisine and Amiens: this was succeeded by the very accurate observations and the trigonometrical survey made by Delambre and Mechain; the terrestrial arch it embraced extended over nearly 10 degrees, and it was almost exactly bisected in the parallel of 45 degrees: these observations, made during the great revolution, led to a more exact method of measuring, and to the adoption of the trigonometrical system of surveying. After the labours of Delambre and Mechain, Biot and Arago carried a train of triangles southward as far as Tormentera, which is a small island near Ivica, in the Mediterranean.

It must always be borne in mind, that the magnitude of the angles of the connecting triangles are affected by the earth's curvature, and these must undergo a correction correspondent with it before the length of the unknown sides can be accurately obtained; for we know that triangles drawn on the surface of the globe cannot be regarded as plane, neither can horizontal angles at one station be considered as in the same plane with those at

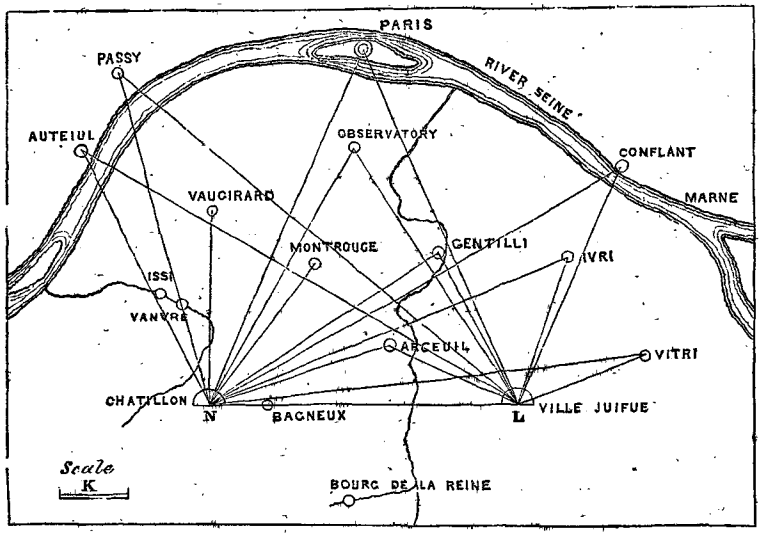


Fig. 972.

another: N L, the original base from whence the triangulation commences, may represent the meridian line; but before we commence our computations we must correct any imperfections in our instrument, or carelessness in taking our survey; we shall afterwards find much advantage by adopting the approximating theorem of Legendre, who first demonstrated that if each of the angles of a small spherical triangle be diminished by a third part of the spherical excess, their sines become proportional to the opposite sides of the triangle, considered as spherical. The situations of Paris and the several towns in its neighbourhood were accurately laid down by the observations made from this base line, and hence commenced the method now adopted in making a trigonometrical survey.

In 1784 the British government turned its attention to this interesting subject, and by Mr. Fox's direction, who was then minister, it was ordered that by means of a series of triangles, the difference in the longitude between the observatories of London and Paris should be ascertained: the meridian of Paris having been already continued to Dunkirk, the Royal Society undertook, with the assistance of General Roy, to complete the task; and he commenced laying down a base line, rather more than 5 miles in length, upon Hounslow Heath.

To connect the triangulations between Paris and Dunkirk, Cassini, Mechain, and Legendre were employed by the French government, and, as a check on their operations, another base line was laid down in Romney Marsh in Kent, where a steel chain, constructed on purpose by the celebrated Ramsden, was made use of. Romney Marsh is 60 miles from Hounslow, and when the two bases were united, by calculating the sides of all the triangles taken, so great an accuracy had been observed, that there was only the apparent error of 28 inches: the junction of the two observatories of Paris and Greenwich was completed in 1788.

Heights may be measured by the demicircle.

The height of the tower at A, the top of which we will suppose is not to be approached, may be measured by placing the instrument at C, in such a manner that by elevating its plane perpendicular to the horizon, through the pinnules of the diameter, which are parallel with the horizon, the tower A B is seen in some point, as at E. Then elevate the alhidade of the demicircle until the top of the tower is visible through its pinnules: remark then on the demicircle how many degrees are intercepted between the diameter and the alhidade, in order to ascertain the angle E D B, which is here supposed to be 20°.

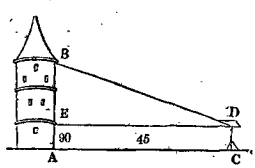


Fig. 973.

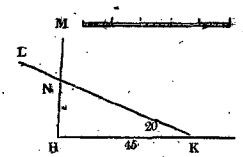


Fig. 974.

Then measure on the ground the distance from the station to the tower, and afterwards construct a scale and lay down a similar figure, the lines M, H, showing the plan of the

tower, the distance, K H, being 45 yards; the angle taken at K, 20° being first set out, it will then easily be perceived that the height may be ascertained by the scale.

The height of the observatory O P from the station at R, may also be accurately ascertained by constructing the angle Y T V, and setting off the distance T X, and then measuring by the scale the height X a. The angle Z X T is here a right angle, and the distance from T to X is 17 yards.

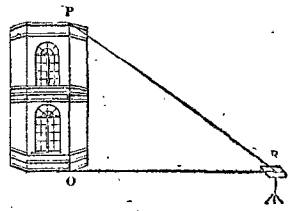


Fig. 975.

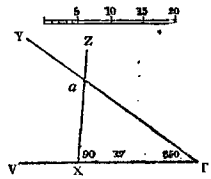


Fig. 976.

Inaccessible heights may be measured by having two stations, as C and D: after the distance between them is ascertained, take the angles B C D from the station C, and the angle B D C from the station D: then construct the angle L G O, and the angle G I M, and by means of the scale the height O N may be measured, which will correspond to the height A B.

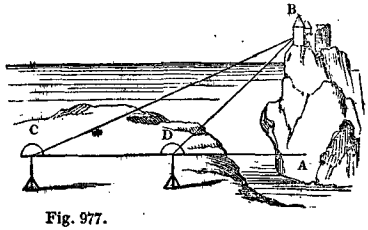


Fig. 977.

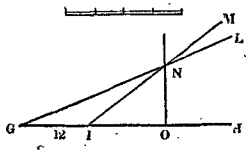


Fig. 978.

The height from P to R may be ascertained in a similar way: from the point S, measure the angle T S R, and from the point T the angle S T R, also the distance between the stations S, T: then construct a scale Q, draw the line V K, and set off the measurement of the distance taken between S and T, which is V X: at V and X set out the angles taken at the two respective stations; the height Z Y will be that of P R.

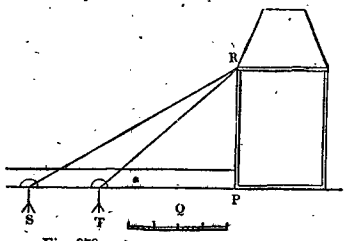


Fig. 979.

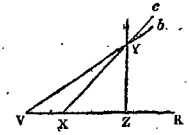


Fig. 980.

The height of the tower A B, which is inaccessible, may also be found by means of the demicircle placed at D C: after the observations have been made, draw the line G H by the scale: from the point G draw the angle G K L equal to the angle C D A, and the angle I N M equal to D A B: the dimension or length of line P O by the scale will be the height of the tower A B.

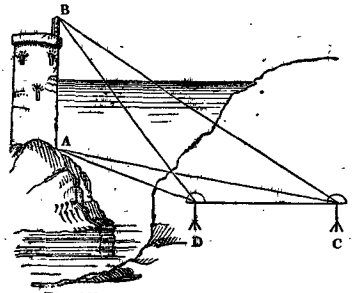


Fig. 981.

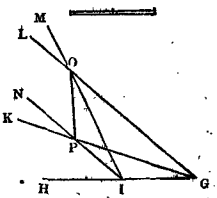


Fig. 982.

The height from one portion of a building to another may also be readily found, as the difference between the levels at R and S: place the piquets at V and T, and measure the four angles T V R, T V S, V T S, V T R, and also the distance between V and T.

Then by aid of a scale up the base line, Z Y, set out the angles so taken at a and Y, as $c\,a$ Y, f Y a, and draw the line $g\,f$ from the point where the lines e, b cross, to where the lines c, d intersect each other, and this line $g\,f$ measured by the scale will be the height required.

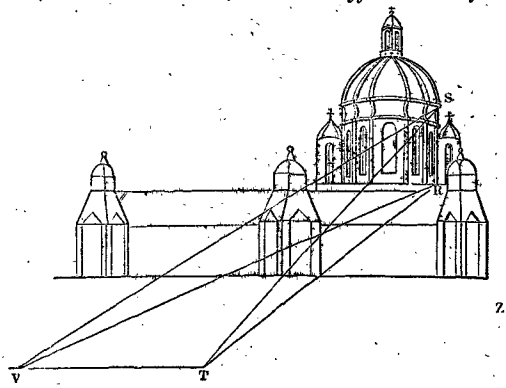


Fig. 983.

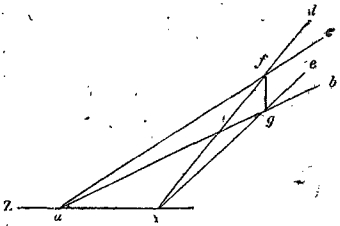


Fig. 984.

The height of the tower A B may be ascertained from the station at D in a similar manner. First take the height of the tower C D, and then place the demicircle at D, in such a position that its diameter shall be parallel to the wall of the tower, D C: turn the alhidade towards the point A, at the foot of the great tower, and measure the angle C D A, the angle D C A being a right angle. Keeping the demicircle at D, place it in such a manner that its graduated limb shall be uppermost, its plane perpendicular, and its diameter parallel with the horizon, as well as with the ray D E: then turn its alhidade until the top of the tower B is seen: the degrees intercepted between the diameter and the alhidade will be those of the angle E D B. Construct a scale K, and set out the figure N I K on the base line F G: make G I on the line H, the height of the small tower; and the height K N, on the line K L, will be the height by the scale.

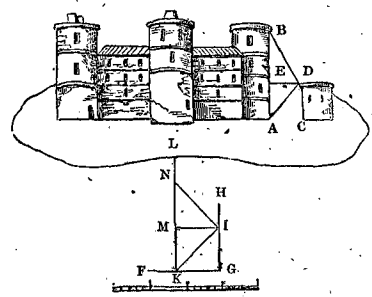


Fig. 985.

The height of the tower O P may also be obtained by placing the demicircle at R, on the top of a lower building, the height of which must be measured. Having observed the two angles P R T and T R O, keeping T R as a level line, and setting off the same angle from Z by the scale, making X Z the height of the low building, and raising a perpendicular on the line Y Z, where the angle cuts the ground: where this cuts the line 4 Z, as at 8, will be by the scale the height of the tower O P.

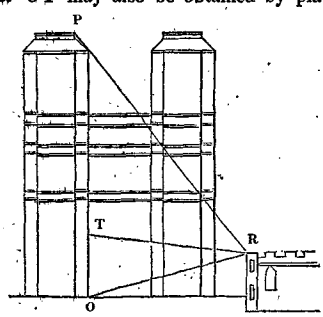


Fig. 986.

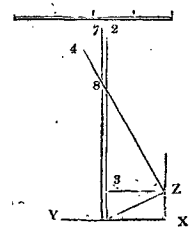


Fig. 987.

We must always bear in mind when measuring angles, that the circumferences of different circles are proportional to their radii, and that similar arcs of circles are also proportional to their radii, and *vice versâ*. Two arcs of different circles, which bear the same ratio to their respective radii, must be similar, and therefore consist of the same number of degrees, minutes, and seconds; it follows, then, that an arc of one second of all circles is contained the same number of times in their radii, and from the calculation of the ratio of the circumference of a circle to its diameter, it is ascertained that this number differs from 206265 by only a fraction; therefore the radius of any circle

differs from an arc of that number of seconds only the fraction of a second. In plane geometry we consider angles as belonging to triangles which do not exceed 180 degrees, but we may fancy them of unlimited increase or diminution: if a line, for instance, revolve round a central point, it will in a revolution move through 360 degrees, and in a revolution and a quarter, that number with the addition of 90. If we call 180 degrees π, the revolving radius in every revolution will move through the angle 2π, and in every quarter of a revolution $\frac{\pi}{2}$, and in every half revolution through π. In general, if n be an integer, the radius after a number of complete revolutions will have moved through an angle expressed by $2n\pi$. If it has exceeded a complete number of revolutions by an angle ω, the angle which it has described will be expressed by $2n\pi+\omega$, and if it fall short of a complete number, it will be expressed by $2n\pi-\omega$. If the angle it has described exceed an exact number of revolutions by half a revolution, we shall get its expression by changing ω into π in the former formula, which gives $2n\pi+\pi=(2n+1)\pi$. If, in like manner, the angle which the revolving radius has moved through exceed or fall short of a complete number of revolutions by a right angle, its expression will be found by changing ω into $\frac{\pi}{2}$ in each of the formula, which gives

$$2n\pi+\frac{\pi}{2}=(2n+\tfrac{1}{2})\pi, \text{ and } 2n\pi-\frac{\pi}{2}=(2n-\tfrac{1}{2})\pi.$$

The angle $\frac{\pi}{2}-\omega$ is called the complement of ω, and the angle $\pi-\omega$ the supplement of ω.

To find the length of the inclined line A B, fix two piquets, one at C and the other at D, and measure the angles D C A and D C B, the first being 27°, the other 42°. Then from the piquet D, measure the angles C D B, 120°, and C D A, 142°: then measure the distance between the piquet C D, which is 9 yards: construct the scale E, and set off on the line F G nine parts taken from the scales, and then construct the two angles I F H and K G L, and the distance from their points of intersection will be the length required.

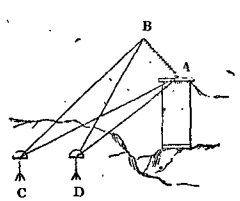


Fig. 988.

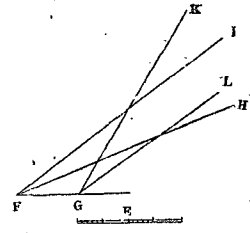


Fig. 989.

Heights that are inclined and inaccessible may also be measured, as that of the Leaning Tower at Pisa. From the stations R and S, from whence may be seen the base and summit, plant two piquets: then place the demicircle at the piquet R, and measure the angles S R O and S R P: place the demicircle at the piquet S, and measure the angles R S P and R S O, and measure the distances between the piquets R, S: lay this down upon paper, and from the points where these angles unite or cut, as at c and d, measure the length cd by the scale, and it will give the inclination of the tower, or rather its inclined height.

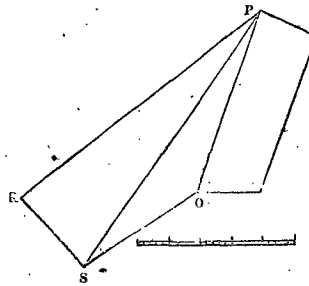


Fig. 990.

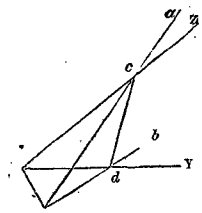


Fig. 991.

Depths which are inaccessible can also be ascertained, as that of the well A: measure the diameter A B, and at the point B measure the angle A B C with the demicircle and by a scale of parts; the perpendicular A C, or depth, may be ascertained by drawing the right angle C F I, and setting out the angle H L K, and from the scale taking the height L F.

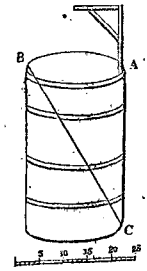


Fig. 992.

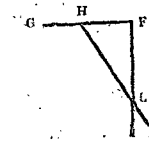


Fig. 993

To measure the depth of a shaft, as M N, the width or diameter at top M O being 9 feet: place the demicircle at O in such a manner that the degrees may be downwards, and its diameter parallel with the horizon, as is the line O M. Then turn the alhidade until the bottom of the shaft at N is seen; measure the angles M O N and O M N; draw the scale P, and the right line R S, and set off the 9 feet from R to T, then draw the angle T R Y; and the height R Y on the perpendicular R V, as measured by the scale, will be the depth required of M N.

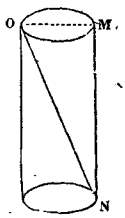


Fig. 994.

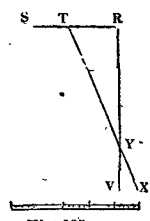


Fig. 995.

The breadth of a ditch may also be found, as that of A B. Being stationed at C above the point A, take the depth C A, and measure the angle A C B. Then with a scale set out on the line E F, and from E draw the angle G E H, and at the point G the angle E G I, which answer to those previously measured. From the point L, where the two angles cut, measure the length G L by the scale, which will be the breadth required.

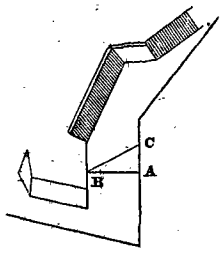


Fig. 996.

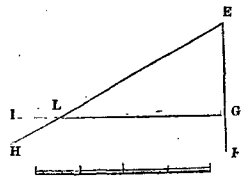


Fig. 997.

The width of the ditch at N may also be found in like manner: from the point N, measure the angle K N M and the angle N K M, and draw the scale O. Draw the line P R, and set off the height taken from N to K, as P S. At the point P, draw the angle S P T, and from the point S the angle P S V; then from the point X, where they cross, measure S X by the scale, and the breadth of the ditch will be ascertained.

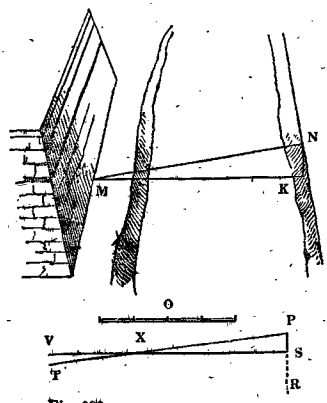


Fig. 998.

The various methods of measuring heights by angles are supposed to have had their origin in Egypt, from whence they were introduced into Greece by Thales: there can be no doubt that after Pythagoras had discovered that celebrated proposition concerning the square of the hypotenuse, trigonometry made rapid advances: we have mention made by Vitruvius of many philosophers who advanced the science of computation by clearer definitions in geometry.

The Geometric Square is an instrument for measuring distances and heights, &c., and is valuable for its portability as well as for the facility, by the common rule of three, of solving most of the problems arising from its use: it is made of brass about 12 inches square, or of wood 15 or 18 inches square: it is graduated from top to bottom, and from bottom to top, and may be called a quadrant of 90 degrees. The two sides of the square which are opposite to the angle of the centre D, as on the sides A B and B C, are each divided into 100 equal parts, which commence at the two extremities of the quadrant, so that in both divisions the hundred-point finishes at the angle B, which is opposite to the centre D, and to facilitate the counting these degrees they are divided into tenths by short lines tending to the centre.

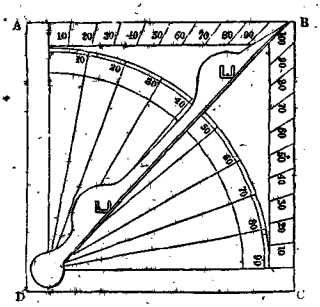


Fig. 999.

The side D C represents the horizon: at the centre D is fixed an alhidade by means of a screw, which equals the diagonal of the square A B C D, on which the same divisions are marked as on the side of the square, and as the alhidade is longer than the side of the square, it will contain more than 100 equal parts: two sights are attached to it, and a socket joint to one side for the purpose of turning or elevating it when required.

Distances between objects when one is accessible are measured by placing the geometric square at the station R, in such a manner that by boning along its side D A, we can discover the point T, and by the other side D C, the piquet or point X at any distance from it; the line D T will then make a right angle with the line D X. Place the centre of the square at the piquet X, and turn it in such manner that by boning along the line D A the piquet R is seen, and by the sights of the alhidade the point T: then remark the number of equal parts in the angle made on the side C B, as at Y.

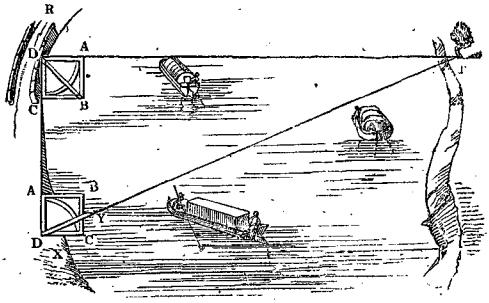


Fig. 1000.

Place, in the first term of a rule of three sum, the number of equal parts from the point C of the square to the point Y. In the second term, place the number of feet between the two stations or centres of the geometric squares D, D; and lastly, for the third term, the number 100 for the number of equal parts into which the side C B is divided. The quotient will give the distance in feet from the piquet R to the point T: if it be desired to find the length of the hypotenuse X T, place in the first term the value of D C of the square; in the second the number of feet from R to T, and in the third term the number of parts marked on the alhidade, which are counted from the centre of the square to the place where the alhidade is on the side C B, as at the point Y. The quotient will give the distance X T.

Distances between objects which are inaccessible are found by the geometric square, by first placing it at the point R, where a piquet is fixed, and then boning a line along its side D A, until the point T is visible. Then in the visual ray formed by the side of the square D C plant the piquet V. Place the geometric square at the piquet V in such a manner that by boning along its side D A the piquet R is seen, and by the alhidade the point S; then count the number of divisions comprised between the points C and Y, where the alhidade rests. Then by the rule of three proceed as before.

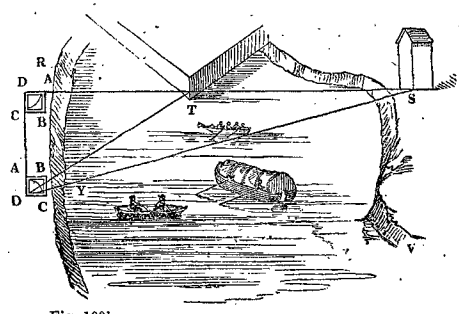


Fig. 1001.

Heights may be measured by the geometric square when the foot is accessible, as by placing the instrument at the point R, and fixing its plane perpendicular to the horizon, in such a manner that the side C D shall be parallel to it: elevate the alhidade, until the point P is obtained through its sights, and remark when it stands on the side C B of the square, as at the point B, where the 100 divisions of the side C B are finished.

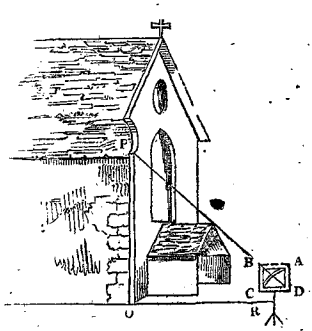


Fig. 1002.

Then by the rule of three, place for the first term 100 for the side of the square C D; in the second the number of feet from the centre D of the square to the point O, and for the third term 100, the number of parts comprised from the point C to the point where the alhidade is at the angle B, as before mentioned. The quotient, which in this case is the distance, will be the height, to which, however, must be added the height the foot of the square is from the ground, when the observation is taken.

If it be required to measure a building with such accuracy that the proportions of its several ornaments and detail should be expressed in a drawing, the only method that can be adopted is, to take the dimensions of each portion in feet and inches with rules or rods prepared for the purpose.

To find the height of the upper part of a tower, as that from O to P. First find the height from the ground at S to O, then measure the distance to the station R. Elevate then the alhidade until you catch the point P; remark where it stands on the side A B, as at Z; let R be distant 38 feet from S, and the height S O, for example, be 34 feet, and the number of parts on the instrument from A to Z 40. Then as 40 : 38 :: 100 : 95, to which add the height of the square, and we obtain the whole height of the tower; from this sum subtract the height S O, and the remainder will be the height from O to P.

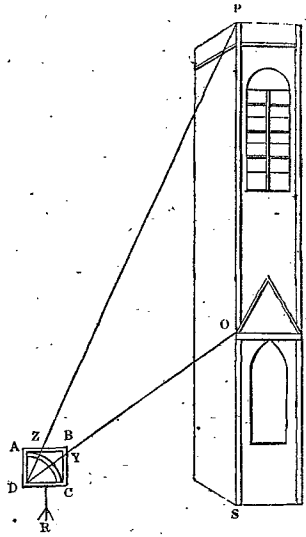


Fig. 1003.

It is a well-known property of a right-angled triangle, that if the ratio of any pair of its sides be known, the angles and ratios of the other sides may be found; this is indeed the principle upon which trigonometry is formed; as there are three pairs of sides in a right-angled triangle, differently related to either of its acute angles, so there are three ratios which will determine the angle.

Let w be the angle, y the opposite side, and x the containing side, and v the hypotenuse; the angle w may be indifferently determined by any of the three numbers, $\frac{y}{r}$, $\frac{y}{x}$, $\frac{r}{x}$. The first $\frac{y}{r}$ is the sine of the angle w, the second $\frac{y}{x}$ is the tangent, and the third $\frac{r}{x}$ is the secant.

Heights of Objects which are not accessible may also be taken, for instance placing the geometric square at the station V, so that its centre is level with the point R: turn its plane obliquely in such a manner that by boning along the side D A, the point T is seen, and by boning along the side D C, a piquet can be placed in the visual ray, as at X, measured at a certain distance from the station V. Then remove the square to the piquet X, and turn it in such a manner that by boning along its side D A, we see in the line the piquet V, and by the sights of the alhidade the point T. Remark the number of divisions from C to Y, where the alhidade stands, and state the rule of three sum by placing for a first term the number of divisions from C to Y; in the second term the distance in feet from the two stations V and X; and lastly 100 for the third term, being the side A D: the quotient gives the line V T. For the second operation, place the square at V, so that its centre shall be exactly in the same place as before, and its plane perpendicular to the horizon, and its side D C parallel to it. Then elevate the alhidade until the point T is seen through its sights, and remark where the alhidade stands on the side C B, as at the point Z.

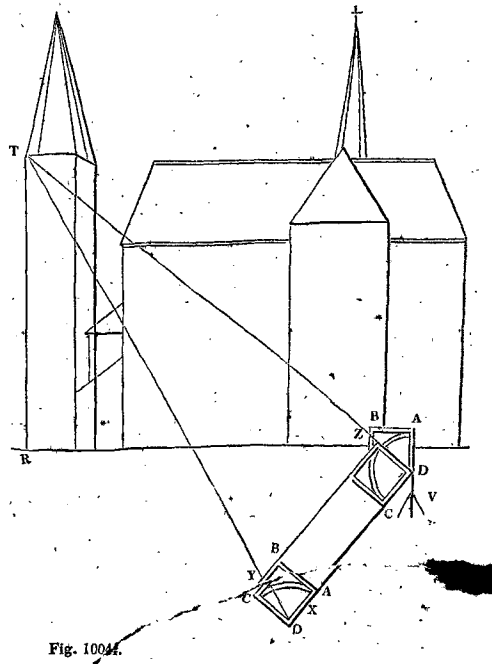


Fig. 1004.

By the rule of three, place for a first term the parts on the alhidade, in the second the distance in feet from V to T, and in the third the number of parts in the instrument counted from C to Z. The quotient thus obtained, added to that found by the first operation, gives the height of R to T.

Of the Sector, and its uses for measuring distances, &c. This is a more complicated instrument than the others previously described, and is usually made of either ivory, wood, brass, or silver, having its two limbs D B and D C 6 or 8 inches in length, when used for drawing, and 12, 15, or more, for making surveys; the largest sectors are the most accurate, on account of their divisions being larger. The limbs of the sector are perfectly flat, and contain all the lines necessary to be drawn on them; they are united at one end by a rule joint with a dot in the centre of the screw, round which it works: when the instrument is closed, the two limbs are called the upper and lower: each face of the sector has a particular name, as that which has the line of equal parts is called the face of equal parts, and another the face of chords. By the line of chords, the opening of angles is ascertained in making a survey, and upon this the sights. F, F, are placed with screws for directing the visual rays. For surveying, the instrument is placed upon a staff by means of a joint with one or more screws, by which any motion may be given it, and a plumb bob is attached, which indicates on the ground the precise centre after an observation has been taken. The sector has two faces, one of which is that of equal parts, the other that of chords, and each face has two branches, which are again divided by three lines; besides the lines of equal parts which it contains, there are also the line of plans and polygons; on the face B, which is the reverse of A, the line of chords is added to those of solids and metals. The lines of equal parts is generally drawn from the centre of the sector to the third part of the four into which the end of each branch is divided, and its length is that of the sectors, which is divided generally into 200 equal parts or [illegible]e. This length is first divided bef[illegible]nalf, so that it may have the 100 marked in the middle; and each of these 100 is again divided in 50 points, and so on until the 200 parts are set out.

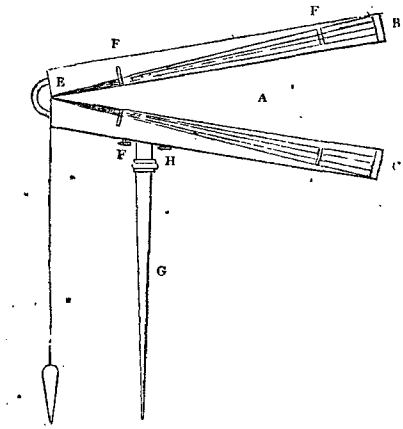


Fig. 1005.

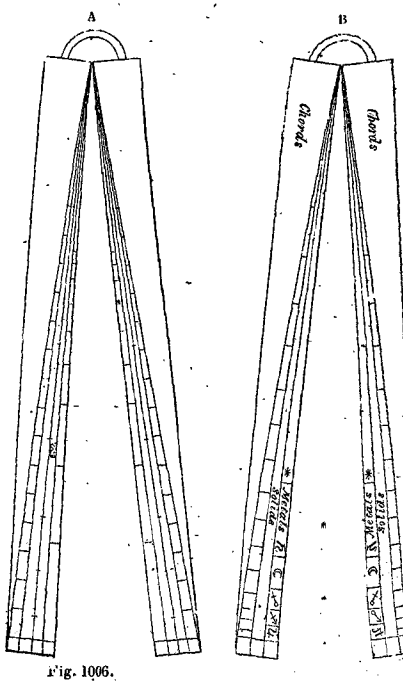


Fig. 1006.

The division of the line of plans is set out from the calculations of equal sides of equal squares, as it comprises between its points the lengths of equal sides of a certain number of square planes, which commonly are enumerated up to 64, and a tolerable skill in the use of the square root is required to find the distances of these points: the first point on the

line of plans is placed opposite the 25th division on the line of equal parts, and the second point opposite 35½, and continued as in the following table.

1	opposite	25	17	opposite	103	33	opposite	143 9/10	49	opposite	175
2	—	35½	18	—	106	34	—	146	50	—	176 7/8
3	—	43¼	19	—	109	35	—	148	51	—	178½
4	—	50	20	—	111 7/8	36	—	150	52	—	180 1/8
5	—	56 4/5	21	—	114⅓	37	—	152	53	—	182
6	—	61 1/10	22	—	117½	38	—	154	54	—	183 7/8
7	—	66 1/10	23	—	119 9/10	39	—	156	55	—	185½
8	—	70⅔	24	—	122⅝	40	—	158	56	—	187⅛
9	—	75	25	—	125	41	—	160	57	—	189
10	—	79	26	—	127½	42	—	162	58	—	190⅗
11	—	82 9/10	27	—	130	43	—	164	59	—	192⅕
12	—	86⅓	28	—	132½	44	—	166	60	—	193⅘
13	—	90	29	—	135¾	45	—	167 7/8	61	—	195⅖
14	—	93½	30	—	137	46	—	169½	62	—	197
15	—	96 5/10	31	—	139¼	47	—	171½	63	—	198½
16	—	100	32	—	141½	48	—	173⅓	64	—	200

The lines of polygons are constructed by the division of circles, or by the proportion it bears to the line of equal parts.

12	is opposite	60	9	is opposite	80	6	is opposite	116	4	is opposite	163
11	—	65	8	—	88	5	—	136	3	—	200
10	—	72	7	—	101						

The division of the line of chords or angles is so named from its forming all kinds of angles, either on paper or on the ground; it is generally the same length as that of the equal parts, and is always divided into 180°, the number of degrees which a demicircle contains.

The line of chords is set out by describing from its middle, K, as a centre, with the radius K H, the semicircle H L C, which must be divided into 180 parts or degrees, so that the line of chords shall be the diameter of the demicircle H L C. From the point H, the centre of the sectors, place one foot of a pair of compasses, opening them to the first point of the division of the demicircle, and describe an arc from thence cutting the line of chords at the first point of its division: then from the same centre H, describe an arc from all the other divisions of the demicircle cutting the line of chords H C: it will then be found that this line will be divided into 180°, commencing their enumeration from the centre of the sector at H.

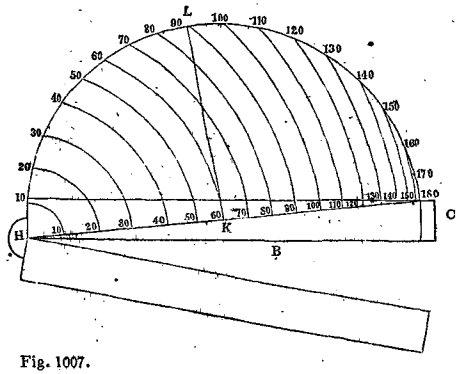


Fig. 1007.

The ancients worked their trigonometry by means of chords and arcs, which, with the chords of their supplemental arcs and the constant diameter, formed all kinds of right-angled triangles. Beginning with the radius, and the arc whose chord is equal to the radius, they divided them both into sixty equal parts, and estimated all other arcs and chords by those parts; viz. all arcs by 60ths of that arc, and all chords by 60ths of its chord or of the radius: this method is as ancient as the writings of Ptolemy, who used the sexagenary arithmetic for this division of chords and arcs.

Menelaus, at the commencement of the Christian æra, wrote six books on the chords of arcs, and his system of trigonometry was greatly improved in the following century by Claudius Ptolemæus, who taught astronomy at Alexandria: in the first book of his Almagest he has a table of arcs and chords, with their method of construction; it contains three columns; in the first are the arcs for every half degree, in the second the chords, expressed in degrees, minutes, and seconds, of which degrees the radius contains 60, and in the third column are the differences of the chords, answering to one minute of the arcs, or the thirtieth part of the differences between the chords in the second column. In this table we discover the property of any quadrilateral inscribed within a circle, viz. that the

rectangle under the two diagonals is equal to the sum of the two rectangles under the opposite sides. This system of computation by chords was changed for that of sines by the Arabians, who improved the science left by the Greek school.

The division of the line of solids is drawn below that of the chords, and of the same length. As the line of planes is founded on the knowledge of the equal sides of perfect squares, that of solids is founded on the cube roots of the equal sides of cubes, which are also marked up to 64. The first point of the line of solids is placed opposite the division 50 of the line of equal parts, and is as follows:—

1	opposite	50	17	opposite	$128\frac{1}{3}$	33	opposite	$160\frac{1}{3}$	49	opposite	$183\frac{1}{3}$
2	—	63	18	—	$134\frac{1}{10}$	34	—	$162\frac{1}{2}$	50	—	$184\frac{1}{2}$
3	—	72	19	—	$133\frac{2}{5}$	35	—	$163\frac{2}{5}$	51	—	$185\frac{2}{3}$
4	—	$79\frac{1}{3}$	20	—	$135\frac{4}{5}$	36	—	$165\frac{5}{6}$	52	—	$186\frac{2}{3}$
5	—	$85\frac{1}{2}$	21	—	138	37	—	$166\frac{2}{3}$	53	—	$187\frac{4}{5}$
6	—	91	22	—	140	38	—	$168\frac{5}{6}$	54	—	189
7	—	$95\frac{3}{8}$	23	—	142	39	—	$169\frac{1}{2}$	55	—	$190\frac{1}{3}$
8	—	100	24	—	144	40	—	171	56	—	$191\frac{1}{4}$
9	—	$108\frac{9}{10}$	25	—	146	41	—	$172\frac{1}{2}$	57	—	$192\frac{2}{5}$
10	—	$111\frac{1}{6}$	26	—	148	42	—	174	58	—	$193\frac{2}{5}$
11	—	$114\frac{1}{2}$	27	—	150	43	—	$175\frac{1}{3}$	59	—	$194\frac{4}{5}$
12	—	$116\frac{4}{5}$	28	—	$151\frac{7}{8}$	44	—	$176\frac{1}{2}$	60	—	195
13	—	$117\frac{4}{5}$	29	—	$153\frac{1}{2}$	45	—	178	61	—	$196\frac{1}{3}$
14	—	$120\frac{1}{3}$	30	—	$155\frac{1}{4}$	46	—	$179\frac{1}{3}$	62	—	$197\frac{1}{2}$
15	—	$123\frac{1}{3}$	31	—	157	47	—	$180\frac{2}{3}$	63	—	$198\frac{2}{3}$
16	—	125	32	—	$158\frac{7}{8}$	48	—	182	64	—	200

The division of the line of metals is divided according to the differences in the calibre of the balls, and each metal is distinguished by its particular sign: that of gold the sign is put opposite $146\frac{1}{2}$ of the line of equal parts, that of lead $172\frac{1}{2}$, that of silver 179, that of copper $187\frac{2}{3}$, that of iron 195, and that of tin 200.

To divide a right line into two or more equal parts by the sector, take its length with a pair of compasses, and carry it to the line of equal parts, then keeping the sector open, carry from the line of equal parts the number which exactly divides it. Supposing it is required to divide the line into five parts, which shall be equal, take its length and set it off on the line of equal parts on the sector at the opening of a number divisible into as many parts as the line is to be divided, viz. it must be remarked, first, what number is divisible by 5, and having observed that 200 is one of those numbers, as 40 is the fifth; place, therefore, the two points of the compasses containing the length of the line to be divided on each point of the 200, which is usually at the extremity of the sector, and keeping it open, then take the distance between the two 40 on the line of equal parts, which distance will be only one-fifth of the length of the line.

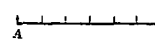


Fig. 1008.

Fig. 1009.

To divide a circle by applying a right line as often as is required: divide 360 by the number of times it is required to apply the given line, and the quotient thus obtained is so many degrees. Then open the sector and carry the length of the given line to the line of chords, where the figures answer to the number of degrees previously obtained: keep the sector open, and take the opening between the two 60° on the same line of chords: this opening will be a radius to describe a circle, which may be divided by the given line into as many parts as is required, or into five, as shown at C D E F H.

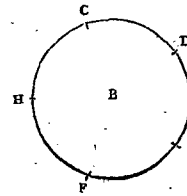


Fig. 1010.

To divide a circle into equal parts by the sector, take in your compasses the length of the radius, and carry it to the two 60° on the line of chords; then divide 360 by the number, as already described. For example, it is required to divide the circle A B C D E into five equal parts: take the length of its radius F B, and carry it to the two 60° on the line of chords, opening and shutting the sector, until the two points of the compasses, open to the extent F B, fall exactly on the two 60° of the line of chords. Keeping the sector at this opening, divide 360 by 5, the number of equal parts required: we shall have 72 as the quotient, which must be taken from the line of chords as before; this opening will then precisely divide the circle into five equal parts.

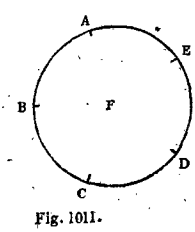


Fig. 1011.

To draw any angle on a right line. — From the point or extremity of the given line describe an arc of any radius, keeping the compasses open; apply it to the sector, opening it until the points fall upon the two 60° of the line of chords: then take the opening on the same line of chords of the degrees of the proposed angle; place one foot of the compasses where the arc touches the given line, and let the other fall on the arc through this point, and that of the extremity of the given line whence the arc is described; draw a right line, and it will be the required angle. As, if it is required to construct at the point A, on the line A B, an angle of 56°, describe from the point A, the arc C D, of any radius: then with the same opening of the compasses carried to the two 60° on the sector, and placed on the line of chords, which must be done by opening the limbs of the sector: then take the distance between the two 56° on the same line, which will be equal to the required angle, and apply it to the arc, when it will touch the point E: then draw a right line through this point from that of A, and the angle B A E will be one of 56°. By the same means the opening of any rectilineal angle may be measured, and its degrees ascertained: great care must be taken always to plumb down the centres of the piquets, as that of C E is found to be at D.

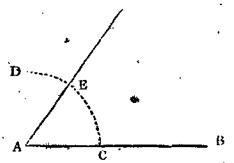


Fig. 1012.

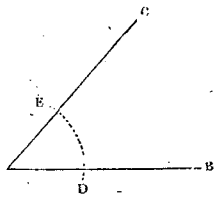


Fig. 1013.

When the sector is used for surveying, the larger it is made, the less liable it will be to error, and too much care cannot be observed in placing the piquet, the centre of which, if planted obliquely in the ground as shown at C, will produce considerable error.

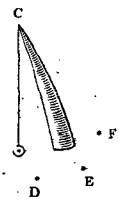


Fig. 1014.

An angle in geometry denotes the inclination of one straight line to another, and in this simple acceptation must be less than two right angles; but in trigonometry the term angle has a more extended signification. Let A B be a fixed line and A a given point in it, and suppose A E to revolve in one plane about A; then the whole angular space described by A E in its revolution about A is called an angle, which may therefore in this case be of any magnitude; or if with the centre A and any radius, we describe a circular arc, subtending any angle A C D, this arc cannot, according to the geometrical definition of an angle be greater than the semi-circumference of the circle; but according to the trigonometrical definition, the subtending arc may be of any magnitude, consisting of any number of circumferences, or any portion of a circumference.

To form and measure angles by the sector: as from the point A to form and measure the angle B A C. Place the sector at the station A, the face of the chords being uppermost, and bone by its sights one of the objects as B, and by the other limb the object C, and the angle B A C will be formed. To measure this angle, take in the compasses the distance between the two 60° on the line of chords, and putting one foot in the centre of the sector, let the other fall on line of chords which will be at 65°, which indicates the angle.

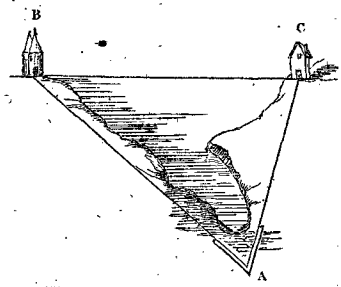


Fig. 1015.

To measure distances by the sector, by forming a triangle of which the two sides are known as well as the comprised angle: as to find the distance between B C, when the two sides D B and D C, with the comprised angle B D C, are known. Place the sector at D, in order to form and measure the angle B D C, which we will suppose to be 83°: then measure the length of its sides, D B and B C, the first of which is 80 and the second 75 feet; this being done, remove the sector from its stand, and turn the under side uppermost, keeping it open at the angle B D C, 83°. Then place one foot of the compasses on the line of equal parts at the figure 80, the number of feet contained in the side D B, and open the other limb to 75 the number contained in D C: this opening of the compasses, measured from the centre of the scale along the line of equal parts, will give 108 feet for the distance from B to C.

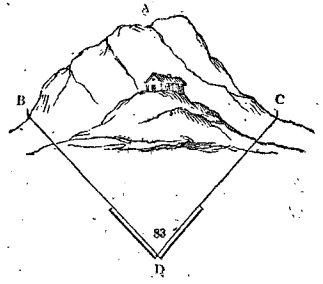


Fig. 1016.

The length of the building from I to K may be similarly found, by placing the sector at L, and then measuring the angle I L K, and the length L I and L K.

To measure distances with the sector by forming a triangle, two angles of which as well as the adjacent side are known: as to find the distance A B, from the base line A C: construct and measure the angle C A B, 84° from the station A, and the angle A C B, 47°, and the base line 134 feet: then to obtain the other angle, A B C, add together the two known angles, and subtract them from 180°, the value of three angles of any triangle, and the remainder, 49°, is the value of the angle A B C. To obtain the length of A B, take in the compasses the length of the side A C, 134 feet, from the centre of the sector along the side of equal parts; then turning the face of the sector, place one limb of the compasses open to 134 at the 98 point on the line of chords, which is twice 49, the value of the inaccessible angle A B C; then leaving the sector open, take from the same line of chords the value of twice the angle opposite the side A B, which will be 94°; this measured on the sector from the centre along the line of equal parts gives 129 feet for the side A B. The side C B may also be found by taking twice the angle C A B, 168°, instead of twice the angle A C B, and following out the same method.

When angles are greater than 124½, its double not being contained on the line of chords, we must, to find this double, subtract 124½ from 180, the remainder, 55½, doubled will give 111 for the double required.

To measure distances with a sector when the objects are inaccessible, as that of the side A B: select two stations at pleasure, as C and D, 42 feet apart, or any other distance. From the station C, form and measure with the sector the angle D C B, which in this case we will suppose to be 40½°, and then the angle D C A, 76½°: from the station D form and measure the angle C D A, 76½° and the angle C D B, 124½°.

These three angles, with the distance between the stations C and D, form several triangles which may be done by the preceding rules, and it will be found that the side C A is 91 feet long, and the side D A also the same dimension. The same rules apply to the other triangles, and the sides C B and D B may be found; and lastly the triangle D A B may be found, the side D A 91 feet, D B 108 feet, and the angle A D B 48°; then following the principle which has been previously explained, viz. the method of measuring by the sector the distances formed by a triangle of which we know the length of two sides, and the angle comprised by them, it will be seen that the length A B is 84 feet.

To obtain heights or distances by means of trigonometry, it is only necessary that the length of one line should be ascertained by measurement, the magnitude of the angles being taken by observation; the sector, as well as the other instruments, are graduated with great precision, but all observations require

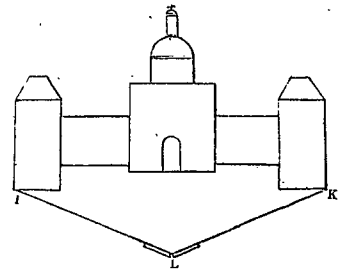


Fig. 1017.

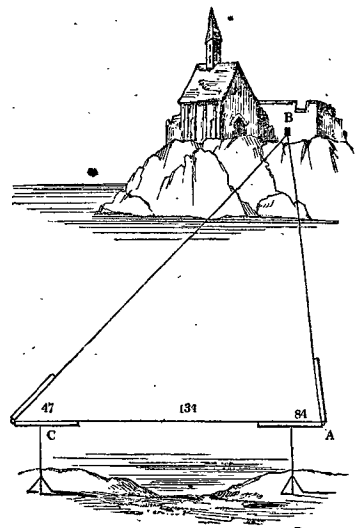


Fig. 1018.

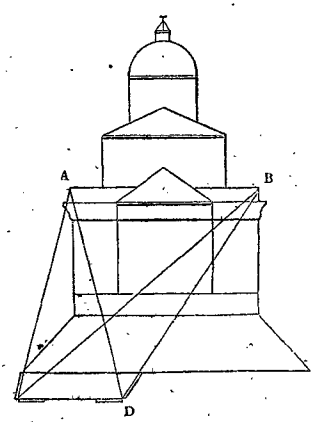


Fig. 1019.

correction by other methods, which do not depend upon the accuracy of the instrument nor the mechanical skill; one of the most important is the principle of repetition, by which any error in the graduation, and in reading off the number of degrees, to which a single observation is liable, is divided among many repeated observations, so that by a sufficient number of repetitions the required angle can be accurately obtained, or nearly so: another method for correcting erroneous graduation and reading off, consists in taking the mean of several readings upon different parts of the instrument.

To find by the sector the three angles of a triangle, when the three sides are known. Take in the compasses from the centre of the line of equal parts the length of the side opposite to the angle to be ascertained, and carry this opening to the same equal parts, and open the sector in such a manner that each foot of the compasses answers to the two other known sides. Keep the sector at this opening, and turn it over; take in the compasses the distance between the 60° on the line of chords, which being measured from the centre of the same line will give the required angle.

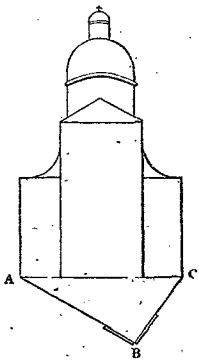


Fig. 1020.

In the triangle A B C the three sides of which are known, viz. A B 10 feet, B C 7, and C A 13 feet, it is required to know the angle A B C. The side C A opposite the required angle being 13, take in the compasses the distance between the centre of the sector and the 13 point in the line of equal parts. Apply this length to the sector, opening and shutting it until each foot of the compasses (open to the 13 parts) answers precisely to 10 feet of A B and the 7 of B C: keep the sector at this opening, and turn it over, taking in the compasses the distance between the two 60° on the line of chords; place one foot in the centre of the sector, and the other leg falling on the same line of chords will indicate 98° 31′ for the angle A B C. By the same process it will be found that the angle B C A is 49° 15′ and C A B 32° 14′.

To measure with the sector heights whose feet are accessible. — The height of the line A B, whose foot B is accessible, is found by taking a station at any distance, as at F, 40 feet, and planting the sector there, mounted on its foot, with its line of chords or visual ray parallel with the horizon. Then lift the other limb of the sector, until the top on the point B is discovered through its sights: this will give 23° for the angle D C B, and as the visual ray cuts the line A B in a right angle at the point D, a triangle will be formed of which two angles and the adjacent sides are known, viz. the angle D C B, 23°, the angle C D B, 90°, with the adjacent side D C 40 feet. The angle C D B will be found by taking the known angle D C B 23° from 90°; the remainder, 67°, will be the unknown angle C B D. To have the side D B, take in the compasses from the centre of the sector, and along the line of equal parts, the value of the known side D C, 40 feet, and carry this to twice the angle C B D, 67=134 on the line of chords. Take in the compasses on the same line twice the angle which is opposite to the required side B D, which will be 46, the angle D C B being 23, and keeping this opening, turn the sector to measure it on the line of equal parts, which will give 16 for the number of feet from D to B, to which sum the height of the sector E C must be added for the whole height of the line A B.

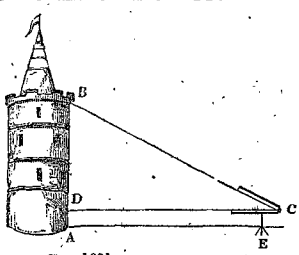


Fig. 1021.

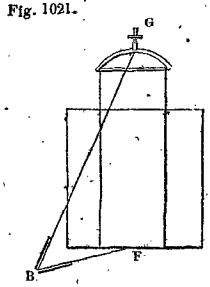


Fig. 1022.

In like manner, by placing the sector at B, the height F G may be ascertained.

The sector is still much employed in France, where it is called the compass of proportion: its principle depends upon the fourth proposition of Euclid's sixth book, in which it is shown that equiangular triangles have their homologous sides proportionals. The scales now put upon sectors are divided into single and double; the former has a line with inches divided into eighths or tenths, a second into decimals containing 100 parts, a third into chords, on a fourth are sines, on a fifth tangents, on a sixth rhumbs, on a seventh and eighth latitudes and hours, &c. &c. The double scale contains a line of lines, a line of chords, another of sines, a fourth of tangents to 45°, a fifth of secants, a sixth of tangents above 45°, and a seventh of polygons.

The single scales may be used when the sector is either open or shut, but the double require it to be opened.

To measure with the sector inaccessible heights, as that of the line A B. Place two piquets or stations, as at C D, in a right line with the inaccessible line A B: measure the distance between the stations C and D, which is 72 feet. Place the sector at these stations, mounted on its foot, to form and measure the acute angle B C D 29°, and the obtuse angle C D B 130°, with the adjacent side D C, 72 feet. To find the sides B C and B D, follow the previous rule, and the unknown angle A B C will be 21°, the side B C 153 feet, and B D 97. To get the height G B and afterwards the whole height A B, observe the triangle D B G, in which the angles G D B and B D G are required: we shall have the first, G D B, by subtracting from 180° the angle C D B, 130°; the remainder 50° will be the value of the angle G D B, and if from 90° we subtract this 50, we shall have 40° for the angle D B G. In the triangle D B G, find the two angles G D B 50°, and D B G 40°, with the adjacent side D B 97 feet. The length G B is known, by the method before cited for measuring distances by means of a triangle, where two angles and the adjacent sides are known, and it will be found that the height G B is 74 feet, to which add 5 feet for the height of the sector, it will be found that the height A B is 79 feet.

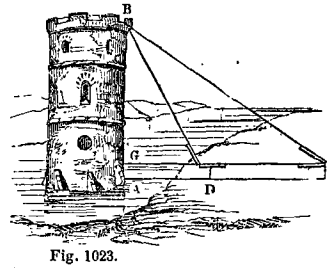


Fig. 1023.

Of the Astrolabe and its application.—This instrument is of wood or brass, and consists of a round plane, a foot or 18 inches in diameter, having two faces, one of which is sunk and called the sea, the other the altimetric scale; it is an ancient invention, and is said to have been in use as early as the days of Ptolemy. The sunk face of the astrolabe contains several lines or bands of metal; the first has engraved on it several stars, and on the others are circles of azimuth, &c. for different elevations of the pole, serving to examine and ascertain the motions of the stars. On the other face, which is used by geometricians, and which comes more under our notice, are several graduated circles, serving to take the heights of various objects above the horizon. These circles are divided into four equal parts by the two diameters A B and C D, of which A B, descending from the ring of the instrument, represents vertical lines, and the diameter C D, which cuts A B at a right angle in the point E, represents the horizon or the level of sea or land. Below the horizontal line C D is an oblong figure F G H I, which is called the altimetric scale, and is composed of two geometric squares, each having two of their sides divided into twelve equal parts. We count from the horizontal line C D, or from the points F and G, the divisions on the sides F I and G H, on which versed shadow is written, and those on the other two sides which compose the long side I H, on which right shadow is written, from right to left of the vertical line A B.

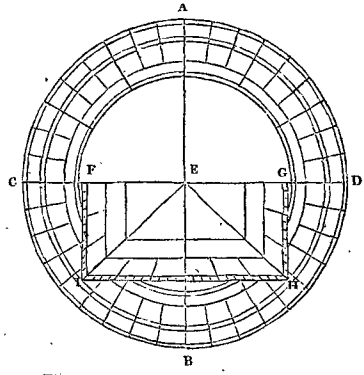


Fig. 1024.

At the centre of the astrolabe is an alhidade fitted with sights, and at the vertical point A of the instrument a ring passes through a movable socket, which serves to suspend the astrolabe in a vertical position.

Measuring distances with the astrolabe, when only one of the objects is accessible: as the distance from the station M to the inaccessible point N, its edge being level with the ground at M. Plant the staff M O, about 5 feet in length, perpendicular at the station M, and divide it into twelve equal parts, without comprising the portion which is planted in the earth. Then, holding the astrolabe by its ring, raise or lower it until in the same visual ray, when looking from the top of the staff O, through the sights of the alhidade, the point N is discovered. Observe then at what point of the altimetric scale the alhidade is standing, as at the third point of the side G H, versed shadow. Then

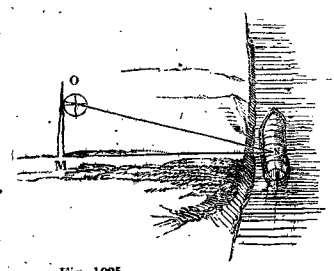


Fig. 1025.

divide 12, the number of parts into which the staff M O is graduated, by 3, the division of the altimetric scale on which is the alhidade: the quotient will give 4, for the number of times that the staff M O would measure in the length M N, and as this staff is 5 feet out of ground, the distance M N will be 20 feet.

When a great length is to be measured, the observer must be mounted at a considerable height, as the astrolabe can only measure twelve times the length of the staff added to the height on which it is mounted.

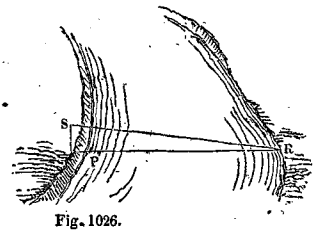


Fig. 1026.

The width of the river from P to R may be ascertained by placing the observer at S, which we will suppose to be 12 feet above the level of the water; then suspending the astrolabe, raise or lower its alhidade until the point R is seen; remark at what point of the scale the alhidade stands, as in this case it is found at 1: divide the height 12 by 1, and the quotient will be 12, which denotes that P R contains 12 times the height of P S, or 144, which is the width P R.

Measuring Heights, whose foot is accessible with the astrolabe, as the height K L. Place the alhidade of the astrolabe in such a position that the line of the alhidade which answers to the visual ray of the two sights shall be exactly in one of the right angles of the altimetric scale, which is found by one of the versed shadows and one of the right shadows. Then suspend the astrolabe from a staff, and holding it in the hand, look at the point L from the end of another staff, through the sights of the alhidade, moving the staff nearer or farther from the line K L, until the point N is seen: lay the staff N, down on the ground in a right line with K N, as at N V, the length V K will be precisely the height of K L.

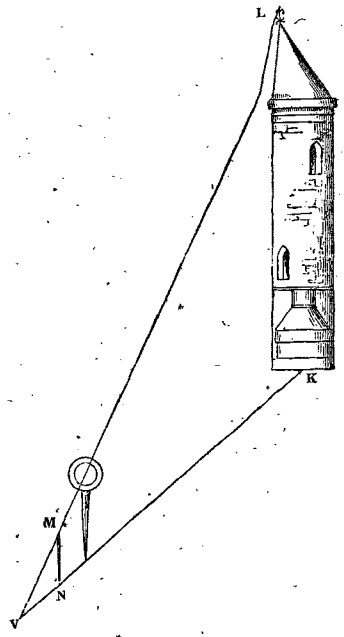


Fig. 1027.

Measuring inaccessible Heights with the Astrolabe. —It may happen that in taking up the two different stations for measuring inaccessible heights, the alhidade, which serves to guide the sight, may in the same operation fall in four different ways on the sides of the altimetric scale, viz.: when in two stations the alhidade is on the same side as the versed shadow; then observe at the first station, which is generally the nearest to the object, at what point on the side versed shadow the alhidade stands; with this number divide 12, and write down the quotient separately: remark at the second station B at what point on the same side versed shadow the alhidade stands, and with this number divide 12 again, and subtract this from the first, or *vice versâ* if it is greater, and with the remainder divide the number of feet between the stations, and the quotient will give the height required by adding that of the staff to it.

Secondly. —When the alhidade at the first station stands at the point 12, or the angle in which the right shadow and the versed shadow meet, and at the second station on the side versed shadow; then remark the number at which the alhidade stands on the side versed shadow at the second station, and with this number multiply the distance between the two stations, and divide this product by the remainder of the points which the alhidade makes on the side versed shadow, to make 12 of the division; this quotient added to the height of the staff will give the required height.

Thirdly. —When the alhidade stands at the first station on the right shadow, and at the second on the versed shadow; then divide 12 by the number to which the alhidade points at each station, subtract the quotients from each other, the remainder will mark that the distance to be known is as many times greater as there are parts to be added to the remainder, besides the height of the staff.

Fourthly. —When the alhidade stands on the *ombra* at both stations, divide 12 by the number at which the alhidade stands at both stations, and subtract one from the other;

multiply the distance between the two stations by 12, and divide this product by the remainder from the subtraction of the two quotients; the quotient of this last division added to the height of the staff gives the required height.

For measuring inaccessible Heights with an Astrolabe, as that of A B, select two stations as C and D, distant from each other in this case 36 feet; suspend the astrolabe at the station C, look at the point A through the sights, and observe at what point on the altimetric scale the alhidade stands, as at the 6 point on the versed shadow. Perform a similar operation at the station D, that is to say, observe the point A through the sight of the alhidade, noting at what point it stands, as at the third point of the versed shadow, which shows that the first of the preceding observations must be followed; divide 12 by 6, the number of divisions which the alhidade indicated on the versed shadow at the first station, and the quotient will give 2: then divide 12 by 3, the number indicated by the alhidade on the side versed shadow of the second station, the quotient will give 4; subtract these two quotients from each other; as $4-2=2$, with which divide the number of feet distant between the stations C, D, 36, which leaves 18 to be added to the height of the staff 5, making 23 feet for the required height, A B.

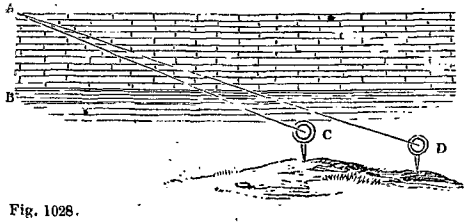


Fig. 1028.

Or if it is required to measure the height A B, in another case, choose the two stations C and D, which here are $27\frac{1}{2}$ feet apart; then suspend the astrolabe at the station C: by the staff and by the sights of the alhidade bone the point A, and mark where the alhidade stands on the altimetric scale, which at the first station will be at the right angle figure 12, where the right and the versed shadows meet: suspend the astrolabe at the second station, and bone the line A through the alhidade, remarking where it stands on the altimetric scale, as at the 8 point in the versed shadow, in which case we must, to finish the operation, employ the second of the previous general rules: therefore, multiply the distance between the two stations C and D, which is $27\frac{1}{2}$ feet, by the number of the side versed shadow at which the alhidade stood, viz. $8 \times 27\frac{1}{2} = 220 \div 4$, the number of points necessary to make up $12 = 55 + 5$, the height of the staff, and we have 60 feet for the required height A B, which is found without approaching the line.

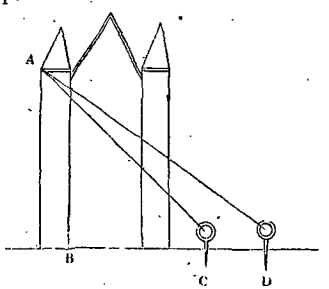


Fig. 1029.

Another method to find the height P R may be described, which is an example coming under the third system. Take a station at any point S, and having planted the staff perpendicularly, suspend the astrolabe from the left hand, elevating or depressing it until the point R is seen from the top of the staff, and by looking through the sights of the alhidades: observe at what point on the altimetric scale the alhidade stands, as at the 4th point of the right shadow, then, according to the third rule, we have $12 \div 4 = 3$; then retire in a straight line to the station S, and plant the staff perpendicular to, and on a level with the point P, suspending the astrolabe also, until the point R is seen, by looking along the staff T, and through the sights of alhidade: after having observed where the alhidade stands, as at 10 on the versed shadow, this number 10 will serve to divide 12, the number of parts on the staff T; the quotient will be 1, which subtracted from 3, the quotient of the first division, there remains 2; this number 2 denotes that the height R P is twice as great as the distance between the station S and T; that is to say, if the distance S T is 8 feet, the height from P to R will be $16 + 5$, when the height of the staff is added: if the difference had been 1 only, then the distance between the two stations with the height of the staff would be equal to the required height. Lastly, if the difference

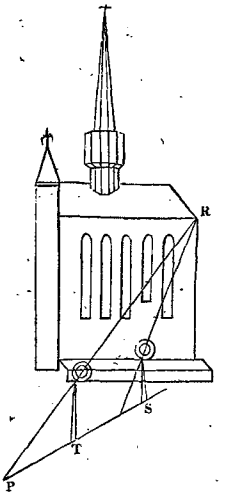


Fig. 1030.

were 6, we must triple the distance between the two stations in order to have a sum, to which the length of the staff must be added, to obtain the required height.

To illustrate the fourth remark, select the two stations R and S, in order that the height from M to N may be obtained; these stations are 40 feet distant from each other: at the station R suspend the astrolabe; bone through the sights of the alhidade the point N, and observe at what division, and on what side of the altimetric scale, the alhidade is, as at the third point of the side right shadow; suspend then the astrolabe at the second station S, and bone the point N through the alhidade, and having observed that it stands at the 10 point of the right shadow, adopt the fourth rule, previously given; accordingly divide 12 by $3 = 4 - 3$, being the number of points on the side right shadow indicated by the alhidade at station R: divide 12 by 10, the number indicated on the side right shadow of the altimetric scale at the second station S; the quotient 1, rejecting the remainder of this division, which is of little account, must be subtracted from the first quotient 4, and 3 remains: then multiply 40 feet, the distance between the two stations by 12, in order to divide the product 480 by 8, the remainder from the subtraction of the two quotients; the quotient of this last division will give 160 feet, to which add 5 feet, the height of the staff, which gives 165 feet for the total height of the line VN; if then we subtract the height from the ground to the point M, viz. V to M, we shall obtain the height MN.

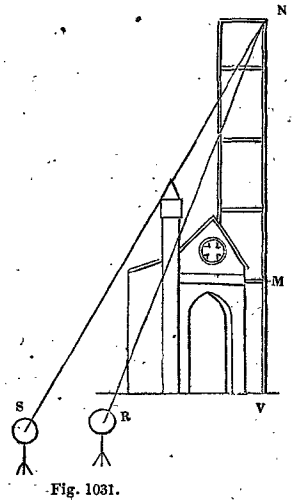


Fig. 1031.

Measuring Depths by the Astrolabe. — Required the depth of a well, as from PM to ON: first measure the opening of the mouth PM, which is 34 inches; then suspend the astrolabe, disposing it in such a manner that the vertical line AB of the altimetric scale, which divides the right shadow into two equal parts, shall be plumb or on the same line with the wall of the well PO: then turn the alhidade of the astrolabe until the bottom of the well N is seen through the sights of the alhidade: remark at what point on the right shadow the alhidade stands; if on the 4th point, as in this case, the depth MN is half the number 12, which is half the division of the long square; therefore, if the diameter of the well MP is 34 inches, the depth MN will be 102 inches, and if we subtract 6 inches for the height of the astrolabe, there will remain 96 inches for the depth of the well. If the alhidade fell on the 6th point of the right shadow instead of on the 4th, the depth of the well would only be twice the diameter of the mouth: if on the point 12, where the right and versed shadow makes a right angle, the depth would be precisely equal to the diameter of the well: if on the 1st point of the right shadow, the depth of the well would be twelve times the diameter of the mouth, and so on with the other points, taking their relation to the number 12.

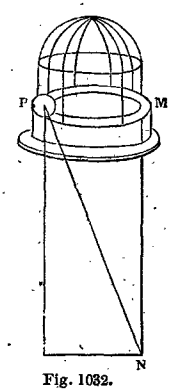


Fig. 1032.

Measuring Heights or Depths with the Astrolabe, when the station is either above or below, as to get the height OP. We must so place ourselves at R that we can see the point O; and at R suspend the astrolabe in such a manner that the line AB shall be perpendicular to the horizon; then turn the alhidade until by means of its sights we discover the point O; observe then where the alhidade stands on the right shadow at the 2 point, counting from the vertical line AB, which indicates that the depth or height OP will be six times greater than the distance RP, because 2 is the sixth of 12, the division of the side of the square used in this operation. Therefore if we measure the distance RP, and find it 12 feet, we shall have to multiply 12 by 6, and the product 72 feet will be the height of OP.

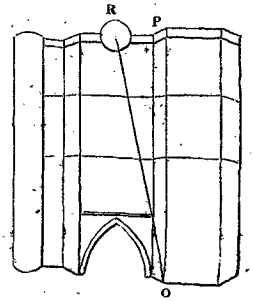


Fig. 1033.

Of the Compass and the Magnetic Needle. — This is usually made of brass or wood in the shape of a small circular box, about 4 or 5 inches in diameter, mounted in a square mahogany case, as shown at G H K I. Each side is divided, and a line drawn across it at right angles; at C, the centre, several circles are described, the outer one divided into 360 degrees; in the centre is suspended the needle; on the top are two sights, through which the observations are to be taken; the box is covered with glass set in a brass rim, the margin of which is divided into 360 degrees. The compass when used is attached by a joint, which enables it to be moved in any direction on the stand provided for it; a ball and socket is usually found to be the most convenient for the purpose.

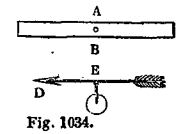


Fig. 1034.

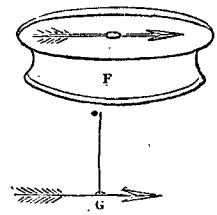


Fig. 1035.

The mariner's compass has a circular card attached to its needle, which turns with it, on the circumference of which are marked the degrees, and also the thirty-two points or rhumbs likewise divided into half and quarter points. The pivot rises from the centre of the bottom of a circular box, called the compass-box, which contains the needle and its card, and is covered with a glass top to prevent the needle from being disturbed by the agitation of the air. The notation is marked out by dividing the circumference into four quadrants by two diameters at right angles, the extremities of which are the four cardinal points marked N, S, E, W. Bisecting each of the quadrants, the several points of bisection are denoted by placing the two letters at the extremity of the quadrant in juxtaposition; thus N E denotes the point which is half way between north and east, and so with N W, S E, S W. Let the octants next be bisected, the points of division are denoted by prefixing to each of the above combinations, first the one and then the other of the two cardinal points of which it is formed. Thus N E gives N N E and E N E, and so with the others: sixteen points having thus been

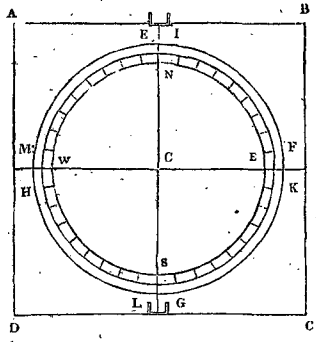


Fig. 1036.

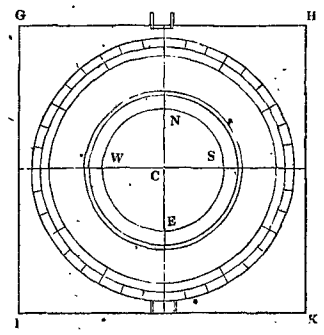


Fig. 1037.

fixed, their distances are to be bisected, and each of the points so found is expressed by that one of the preceding points already named to which it is nearest, followed by the name of the cardinal point towards which its departure from the nearest points leads it, the two being separated by the little letter *b*; thus the point half-way between N and N N E is N b E, that which is half-way between N N E and N E is N E b N: the whole of the thirty-two points are thus established.

The variation of the needle is its deviation from the north; and to find the true meridian of a place by the sun, we may fix a piquet upon a horizontal plane, either perpendicular or inclined, as that at A B, with a plumb attached, as B C: from the point C, which is found by the plumb, and with the radius at which the point of the shadow D finishes before noon, describe the arc D F; then in the afternoon observe where the shadow touches the arc a second time, as at F, and draw the line D F; bisect this line, and raise the perpendicular C G, and this line will be the meridian. By placing the compass at I and K, its variation may then be observed from the true meridian.

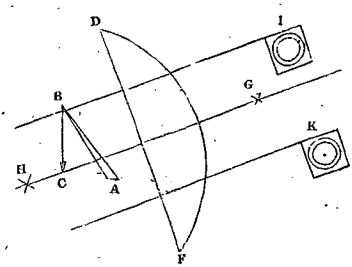


Fig. 1038.

The meridian may also be found by the plane table, as that shown at M L O N; describe on it the arc of a circle M P O, and sink it to the depth of an inch, and then within it describe another arc, as Z, parallel with the first: at L, place a small piquet or staff.

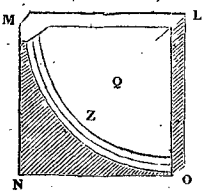


Fig. 1039.

Place this plane table on a level plane about nine o'clock in the morning, as is done at X, so that it stands on its side N O; and having O L towards the sun, turn it until the extremity of the staff at L casts its shadow on the circle at Z, and then mark on the ground the line R X; and after some space of time, observe another point where it cuts the circle: at three o'clock place the plane table on its side N O, with O L towards the sun, taking care that one corner of the plane table touches the line R X, as at the point R; and observe as before where the shadow of the staff touches the circle Z, and having remarked this point, draw along the foot of the plane table the line R S; from the point of intersection, R, describe the arc X S, which bisected in T will be the meridian required.

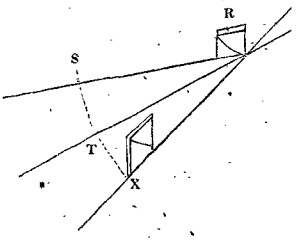


Fig. 1040.

The dip of the needle is subject to variations, to account for which numerous hypotheses have been suggested. Halley once supposed the earth a great magnet, with four poles or points of attraction, two being near each pole; but on reflecting that no magnet was known to possess more than two poles, he abandoned that idea, and imagined the earth to consist of an external shell, which contained the magnetic power, having its two fixed poles distant from the poles of rotation, and an inner globe separated from the outer crust by a fluid, also having two poles, and the same axis of diurnal rotation as the shell. The general opinion now is, that the magnetism of the earth is owing to its temperature; that the globe itself is a great magnet, and the intensity of its magnetism at any point is inversely as the temperature of that point. Those who are desirous of making accurate observations upon the variations to which the needle is subject must have recourse to one of the instruments made expressly for the purpose, as Colonel Beaufoy's variation instrument, so generally employed in his numerous magnetical experiments, or Dolland's dipping needle remarkable for its simple construction, and the adaptation of adjustable agate planes, on which the pivots of the needle rest: for the purpose of proving whether these planes are horizontal, there is a contrivance on the under side, by which their level can be truly ascertained.

A vessel constructed of iron having caused considerable disturbance of the needle, a number of experiments were undertaken by Mr. Barlow of the Royal Military Academy at Woolwich, who found that the attracting power of iron is not resident in the mass, but on the surface; so that a hollow shell of about four pounds weight acts as strongly on the needle, at the same distance, as a solid iron ball of 200 pounds; this being established, it occurred at once that a thin iron plate of five or six pounds weight might be made to represent and counteract the whole amount of the attraction of the vessel, and thereby leave the needle perfectly undisturbed; the action of the ship and that of the plate, as regards their effect on the needle, neutralising each other; upon this principle Barlow's correcting plate is made, which, mounted on a tripod stand or fixed pedestal, determines the variation of the compass in a ship, as dependent upon the local attraction of the vessel.

Maps drawn by the Compass. — The instrument used for this purpose has its rim divided into 360 degrees, and against one of its sides parallel to the meridian is a movable rule or alhidade, the upper edge of which is furnished with a groove to bone the objects either vertically or otherwise, without disturbing the horizontal position of the compass. When a map is to be laid down, two stations are selected from whence the whole of the country can be seen: place the compass, for instance, at the point A, and turn it in such a manner that it points north, and that by boning along the alhidade the point B is seen; remark then how much the needle declines from the meridian of the compass: turn the north side of the compass towards the next object to be boned, as C, remarking the degrees indicated, as 22° W.; write this down on the side of the visual ray, and proceed with the other angles of the position, as that of D, which is 7° W.: then place the compass at the second station B, in such a manner that the north side is towards D, and observe the degrees which are indicated by the needle, as 15° W.; figure this down against the visual ray, from B to D: then turning the north side of the

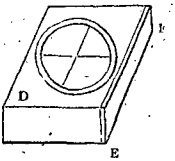


Fig. 1041.

compass, bone its position through the sights of alhidade, and remarking that the needle indicated 45° W., write this against the visual ray.

Draw out the map, tracing a line A B, on the paper, and set out upon it 1600 feet, the distance measured from A to B; against the line A B, used as the base, place the side of the alhidade of the compass, and turn the sheet of paper, keeping the compass against the side A B, until the needle points at the same degree as when boning to A: without removing the paper, observe what is the degree of the ray to C, and having found it to be 22° W., place the side of the alhidade against the side A, and turning the compass, with the side of the alhidade always against the point A, and the paper unmoved until the needle makes 22° W., as found from the point A to C, draw a right line along the side of the albidade of the compass, which must also be done for the other positions as 7° W., for the point D: then observe, where the station B is marked, what is the degree on the line which goes towards C, and having found it 45° W., place the side of the alhidade on the sheet of paper at the point B, the extremity of the line A B; and doing the same at the point B, we shall have second rays which will cut the first in several points, and give the positions of the places to be set down on the map.

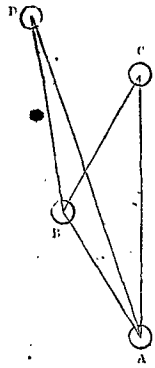


Fig. 1042.

The compass is also used to mark the meridian on maps; this is done by placing against the line drawn from one plane to another, as from A to B, one of the sides of the compass, and then observing the place where the needle points, and marking its direction, as K L; this is afterwards again proved by placing the box against this second line, and finally drawing E F parallel to it.

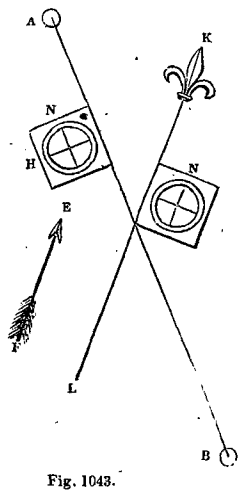


Fig. 1043.

The compass should be extremely susceptible and possessing an intensity of directive force; the first of these is obtained by constructing the needle of the material and form best suited to receive and retain the magnetic power. Shear steel has been found best adapted to receive the greatest amount of magnetic force, and the best form is that of a lozenge or rhomboid cut out in the middle, so as to diminish the extent of surface in proportion to the mass, it being ascertained that the directive force of the needle when magnetised to saturation depends not on the extent of surface, but on the mass.

To measure Angles with a Compass, attach a long rule to its north side, and present it against one of the sides of the angles to be measured, and observe how many degrees the north point of the needle declines from the north point of the compass, beginning to count these degrees from the smallest arc there is from the north point of the card, to the degree where the north point of the needle stops, in order to figure on one side the degree of declination, supposing that the north point of the needle does not coincide with the north point of the compass: then present the same side of the compass to the other side of the angle, and count from the smallest arc how much the north point of the needle is distant from the north point of the card; subtract the degrees from each other, and the remainder from 180°, and this remainder will be the angle required. As in the salient angle B A C, apply the long side marked north of the compass to the side A B, and observe how many degrees the north point of the needle declines from the north point of the card; and since they coincide, it is a proof there is no declination; write therefore, north to the side A B: then apply the same side of the compass to the other side A C, to count how much the north point of the needle declines from the north point of the card, as 90°, write down A C 90°; above mark north, in order to subtract this from 90°, which being subtracted from 180° still leaves 90° for the angle B A C. But if the angle required was C D A, when the north point of the needle is 36° from the north point of the card, having placed the north side of the compass against the other side D B, it will be seen that the declination of the needle would be 92°; subtract the 36° from 92°, there will remain 56°, which being subtracted from 180° leaves 124° for the angle C D B.

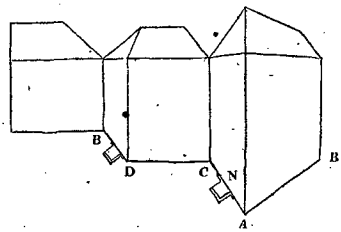


Fig. 1044.

To make Surveys under Ground, as in Mines, with the Compass. — Supposing it required to make an opening at A, and after a shaft has been sunk to the required depth, to cut a road in the mine which shall continue in the direction of and terminate at a point directly under B; we must place ourselves above the opening A, as at C, and then measure in a right line the distance from A to B, which in this case is 28 feet; then place the north side of the compass at the point C, on the line C B, and observe at what degree the needle points, as to the 7° E. of N., and figure this down: then having removed the compass, draw on the ground at the point C, and on the line C B, the perpendicular C G, and lay a staff along this line C G, which carries at its salient extremity a plumb-line, to mark the point H on the ground at A, and also several others, as I K, &c., drawing back the rod on the line C G; take care to observe how much the rod was advanced from the point C, where it marked the point H, as 9 feet: then from the entrance A, draw a right line through the points H, I, K, measuring back 9 feet from H, which will give the point R, answering to the point C above ground: place the side of the compass marked north at the point R, and turn the compass till the needle stops 7° E. of N., which being remarked, draw a line along the north side as R S, in order to dig according to this line from the point R 28 feet, which will coincide with the point B; but should it not be practicable to continue in a straight line on account of the hardness of the rock, or for some other cause, several detours at right angles may be made to the right and left, as shown at O, P, &c., taking care that the number of small detours, P, compensate for the detour O, to find again at V the right line R S.

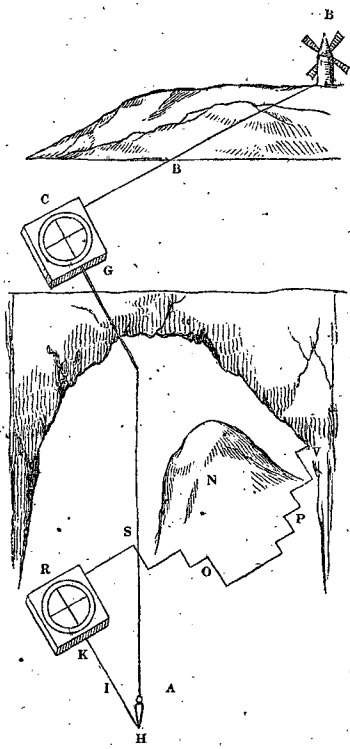


Fig. 1045.

It is by the aid of geometry that the miner studies the situation of the mineral deposits on the surface and in the interior of the ground: he also determines the several relations of the veins and rocks, and becomes capable of directing all the operations which are to be performed. Wherever iron does not interfere with the magnetic needle, the compass is employed to measure the direction of a metallic vein, and its graduated circle serves to notice the inclination or dip, which is called the clinometer. The distance from one point to another is measured with a staff or chain; for some surveys the dials of the compasses are graduated into hours, generally twice twelve; thus the whole limb is divided into 24 spaces, each of which contains fifteen degrees or one hour, which is subdivided into eight parts.

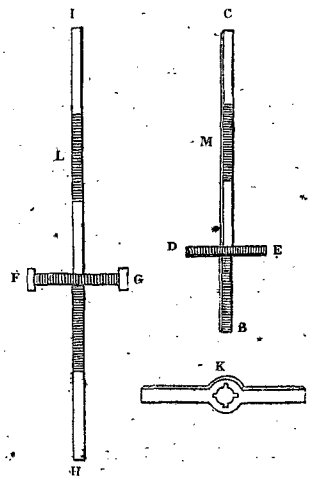


Fig. 1046.

The Jacob's Staff, an instrument used by geometricians to measure distances and heights, is a long rod or square staff with a cross, as shown at D E; it is usually made of the wood of the wild cherry, pear tree, or ebony, these three trees having fewer knots or veins, which allows the cursor to move freely up and down the rod: the rod itself is divided usually into four equal parts, as at M, or five as at L, and is commonly 3 or 4 feet in length: the cursor has a square hole made in the middle, and is allowed to have but little play; it is provided with a small screw to keep it at any required point. In order to measure distances, it should be in

length equal to one of the parts the rod is divided into, and when we wish to measure a height, we must add half the thickness of the rod to the extremity of half the cursor which is used to take the height. In order to bone more easily along the rod of Jacob's staff, four small holes are pierced aside the hole in the cursor, as shown at K; this instrument when used is mounted on a stand fixed to the ground.

To measure the Distance between two Objects one of which is accessible. — Place the cursor on the second division of Jacob's staff, fix a piquet on the ground near the accessible object, and place the end of the rod near the piquet; bone along it until you discover a point of the inaccessible object, and bone with the extremities of the cursor two other points, one to the right, the other to the left of the inaccessible object, and in the same line with the first inaccessible point: run the cursor to the third division of the staff, and retire in a right line from the first station, and from the first inaccessible point, in such a manner that by boning along the rod you can discover the piquet and the point in the inaccessible object, and also the two points to the right and left of the inaccessible point by boning along the extremities of the cursor; the distance between the latter station and the piquet at the inaccessible object will be half the distance between the two objects. The breadth of a river may be found by placing the cursor on the second division of the rod or staff, as at H, and then placing a piquet at A, against which the end, M, of Jacob's staff, is required to bone; which is done by placing it in such a manner that by looking along the staff M N, you can see the point B, and also the two points E and F by the extremities C and D of the cursor: run the cursor on the third point of the rod, as to G, and retire in a right line from the accessible object A, until by boning along the staff M N, and by the extremities of its cursor C D, you discover the inaccessible point B, and also the two others E and F: the distance K A, being doubled, will give the breadth of the river from A to B, that is to say, if it is 30 feet from K to A, it will be 60 feet from A to B.

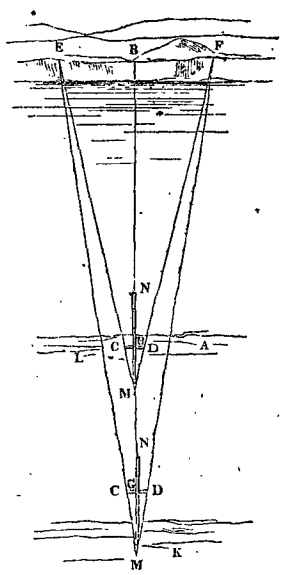


Fig. 1047.

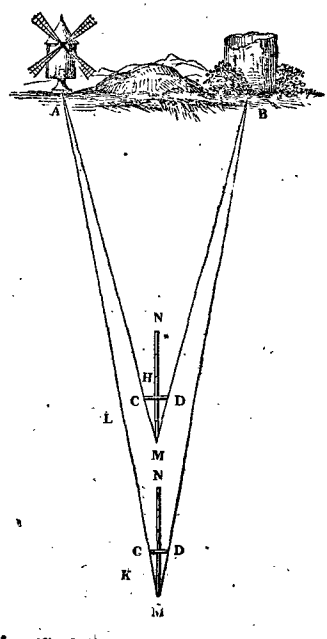


Fig. 1048.

To measure Distances between two inaccessible Objects. — Fix the cursor on the second division of the staff, and place yourself about midway between the two objects which are inaccessible, bone along the staff, and by the two extremities of the cursor, which should be placed in a direction parallel to the line between the two objects, until you discover the two inaccessible objects by the visual rays; plant a piquet at the place where the observation was made: then run the cursor on the third division of the staff, and retire from the first station, boning by the staff and by two extremities of the cursor until you discover by the visual rays the inaccessible objects; the distance between the stations will be equal to that between the objects. As, for instance, it is required to ascertain the distance from A to B: run the cursor on the third division of the staff M N as to H; then being at about an equal distance from both objects, bone by the staff M N and by the two extremities of the cursor, C D, which is parallel with the line A B, the two objects A and B; that is to say, you must discover by the visual ray M C the object A, and by the ray M D the object B, which will be the case when you are at L, where you must place a piquet for the first station. Then run the cursor C D on the third division of the staff M N, as to G, and retiring from the piquet or station

L, bone the piquet L and the inaccessible objects A and B, as was done at the first station, which being observed at the station K, plant there a piquet for the second station. The distance between these two stations or piquets L, K, will be equal to that between the inaccessible objects A, B; that is to say, if it be 180 feet from L to K, it will be 180 feet from A to B.

To measure accessible as well as inaccessible Heights.—Place the cursor on the second grand division of the staff, holding the staff horizontal with the cursor perpendicular to the horizon; advance to or retire from the object whose height is required, until by boning along the staff and the two extremities of the cursor the foot and the summit are discovered at the same time, which when observed, plant a piquet at the station of the same height as the staff is held. Then run the cursor on the third great division of the staff, and advance or retire from the piquet until at the same time the foot and the summit of the object are discovered, remembering to keep the staff horizontal, as at the first station, and bone by the two extremities of the cursor; then plant a piquet at this station: the distance between the two piquets will be that between the objects.

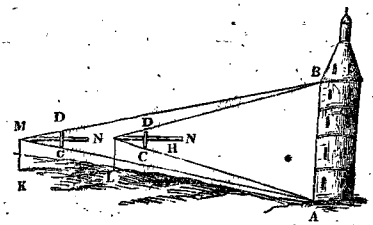


Fig. 1049.

The height of an object, A B, being required, fix the cursor at the second division of the staff M N, as at H; then holding the staff horizontal, bone from its extremity M along the two extremities C and D of the cursor, until the foot A and the summit B are seen, which will be the case at L, where a piquet must be planted, of the height the staff M N is held. Run the cursor C D to the third great division of the staff, as at G; then approaching or retiring from the piquet L, holding the staff horizontal, and at the height of the piquet L, bone from the end of the staff M, by the two extremities C and D of the cursor, until the foot A and the summit B are seen, which will be at the station K, where a piquet must be planted for the second station. Then, measure in a right line the distance between the two piquets K, L, which will be the height required; that is to say, if the distance K L is 80 feet, the height A B will be 80 feet: small heights can only be measured by this means, as the instrument must be placed opposite the middle of the height required.

To measure Lengths when they are accessible about midway.—Stand opposite the middle of the required length, and dispose the staff and cursor parallel to the horizon; bone the two objects by this end of the staff and the two extremities of the cursor, which should be placed parallel to the distance between the two objects; this may be done by moving the cursor nearer to or further from the eye: count how many small divisions there are on the rod between the end of the staff boned and the place where the cursor stopped; measure how far it is from the station whence the two objects were boned to the middle of the line drawn between them: by the rule of three place as a first term the number of small parts at which the cursor stopped on the rod; in the second term the number of feet from the station to the middle of the distance between the objects; and in the third, 30 for the length of the cursor: the quotient will be the answer. The distance from A to B is required, which to obtain we must place ourselves at the station K, opposite the middle of the distance between A and B, and dispose the staff in such a way that the rod and cursor may be parallel to the horizon, in order that, when boning from the end of the cursor C and D, the two objects A and B may be discovered, either by advancing or retiring the cursor back, as to the 60 division. Then measure how far it is from the station K to the point L, which is the middle between the two objects A and B, or 450 feet. Then by the rule of three, placing as a first term 60, the number at which the cursor stands, and in the second term 450, the number of feet from the station K to the middle L, between the two objects

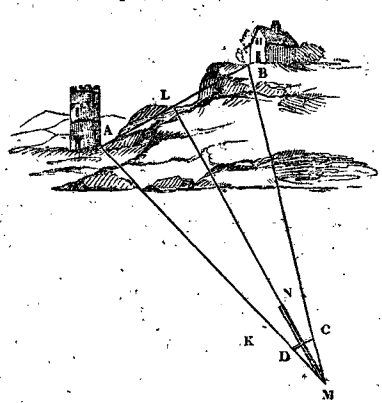


Fig. 1050.

A and B, and in the third term 30, the length of the cursor; the quotient gives 225, the number of feet from A to B.

To measure Heights by Jacob's Staff and Arithmetic.—In this case its rod is placed parallel, and its cursor perpendicular to the horizon; then boning from the end of the rod by the elevated end of the cursor, the summit of the height to be found, which is done by moving the cursor nearer to or farther from the eye, and remarking the number of small divisions on the rod, comprised between the end boned and the place where the cursor stops; then measure the distance from the station to the foot of the required height; put for a first term the number of small divisions at which the cursor stands; for the second the distance in feet from the station; and for the third term half the length of the cursor, the quotient will be the height sought.

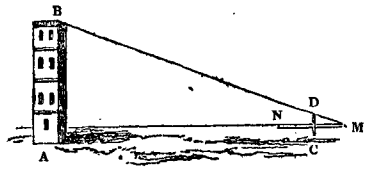


Fig. 1051.

The height A B is required. The staff M N is to be first placed parallel with the horizon, and C D perpendicular to it; in order that by boning from the end M, by the elevated arm D of the cursor, the point B may be seen. Count how many divisions there are on the rod between M and the cursor D, as 45; then measure the distance on the ground to A, which here is 600 feet; then 45 : 600 : : 15 : 200, to which quotient must be added the height of the stand, to obtain the height of the tower A B, 15 being half the length of the cursor C D.

The Plane Table, and the method used for measuring heights and distances, &c. with it. This instrument is of great antiquity, and was clearly in use when Vitruvius compiled his book; it is usually made of a plate of brass, either of a round or square form, on which is placed a sheet of paper to draw the lines necessary to form plans or maps, as well as to obtain the distance between objects. The plane table A for mapping is of brass, 10 or 12 inches in diameter, and on its edge is a circle B, capable of containing six sheets of paper, and having a diameter sufficient for measuring the 360 degrees. In the centre at C a point is placed, the upper part of which is sunk to receive a screw. On the centre is placed a brass alhidade, F G, which fits into the hole C, and which is furnished with a telescope.

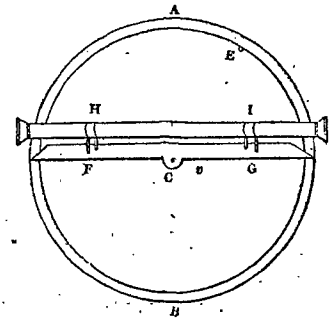


Fig. 1052.

The plane table is often used for forming a sketch map, and for filling up the details of a survey, where the principal points have already been fixed by the theodolite, but observations made with it cannot be relied upon where great accuracy is demanded: in many plane tables the divisions into 360 degrees is dispensed with, and the reverse face of the frame is divided into equal parts, as inches and tenths, which are very convenient for ruling parallel lines, setting out squares and other purposes. On one side is screwed a compass-box, with a magnetic needle to indicate the bearings, and to enable the engineer to place the instrument at any new station parallel to its former position. The brass rule or index with a sloping edge and perpendicular sight vanes at each extremity is all that is required to complete the apparatus.

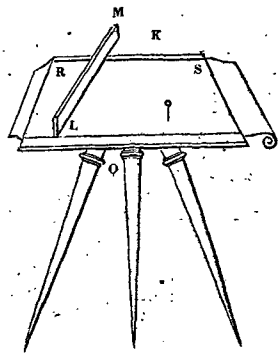


Fig. 1053.

The modern plane table is commonly made of wood in order that pins may be readily fixed in it: its size for taking distances is about 2 feet in length, and 18 inches in width, and about 1 inch in thickness; its station line being only 6 inches. When used a rule L M is placed on its edge to serve for the sights, and we require a stand to place the table on, some piquets, pins, and a chain to measure distances with: a sheet of paper is then

placed on the plane table, folding down the edges, which are secured either with mathematical pins or by paste; sometimes the plane table is sunk, and by means of a frame the paper is kept flat.

When the paper is laid over the table T, the frame V passes over it, and keeps it perfectly stretched and in its place.

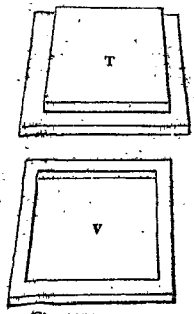


Fig. 1054.

To take the Distance between two Objects, as A *and* B, *which are each accessible from one to the other,* the plane table is placed at any point, as C, opposite the middle of the two objects: draw a scale near one of the long sides of the table, and fix a pin, D, at about an inch from this scale within the table, where the station line generally is; then turn the plane table in such a manner that one of its sides shall be nearly parallel to the two objects A and B: place against the pin D the side of a rule which may be moved in such a manner that when boning along the face of this rule from the pin D, the visual ray may cut the point A: draw on the paper from the pin D along the side of the rule the line D E: then shift the rule to the other side of the pin, and in a similar manner draw the line D F: measure how far it is from the station C to the object A, as 64 feet, and take from the scale G 64 parts, and set them off on the line D E from D to H, to answer to the 64 feet from the station C to the object A: likewise take 66 parts from the scale G, and set them off on the line D F from D to I, to answer to the 66 feet from D to B: draw the line H I, which being measured by the scale G, will give 51 parts for the number of feet from A to B.

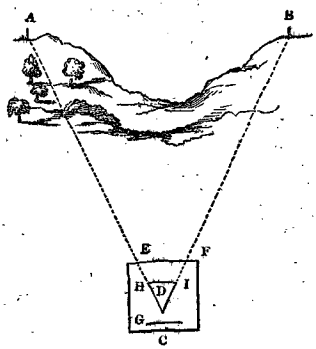


Fig. 1055.

To measure the Distance between inaccessible Objects, as that of A and B: place the two piquets, C and D, at pleasure, and draw on the plane table a scale, E, of any length or division, as into 600 equal parts, and measure the distance between the two stations C and D, as 563 feet: take from the scale 563 parts, which will give the station line F G on the table, on which fix the pins F and G: place the plane table at one of the stations, as at C, in such a manner that the station point F shall be above the piquet C, and the plane table towards the objects A and B: bone the piquet D by the two pins F and G, keeping the table in this position; place a rule against the pin F, and bone the object A along the side which touches the pin and draw the line F H. Then turn the rule against the pin, until the object B is seen, drawing in the plane table the line F I: remove the plane table from this situation to the piquet D, placing it in such a manner that the point G of the station line shall be exactly above the piquet D, so that by boning along the pins F and G the piquet C may be discovered: place the rule against the pin G, and bone the object A along it, drawing on the table the line from the pin G, along this rule a line G K, and remark where it cuts F H at L: turn the rule until the object B is discovered, keeping the rule against the pin G, and draw on the plane table along the rule a line G M, and observe where the line G M cuts F I, as at N: the length L N measured by the scale F will give 342 feet for the inaccessible distance A B.

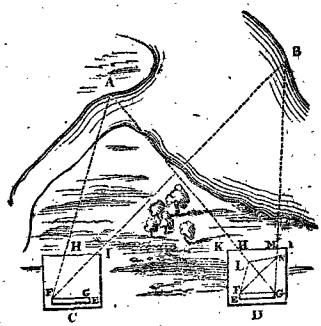


Fig. 1056.

In this figure two stations are selected as the extremities of the base line, the distance between which is accurately measured, and represented by a line drawn on paper, according to the assumed scale: if the modern plane table be used, it is set up at one of these stations, and a fine needle or pin being stuck into the table at one extremity of the line drawn on the paper, the edge of the index is brought to press gently on the pin, and coincide with the line and the table turned round, till the object of the second station is bisected through the sight vanes; the table is then clamped, and the direction of the magnetic meridian marked; the fiducial edge of the index, still kept in contact with the upright pin which serves as a centre, is then directed successively to the objects A and B, and lines drawn on the paper in the direction of each; when this is done, the table is removed to the other station, and the pin placed at the correspondent point on the paper, which forms a second centre. The edge of the ruler is then directed to A and B as before,

when the intersection of the several lines drawn from the second centre, with those drawn from the first, marks on the paper the position of A and B.

To measure the Bends of Rivers, as that of A B C: plant at pleasure the two piquets H and I, and measure the distance between them, as 200 feet: draw on the plane table the station line K L, which divide into 200 equal parts, to serve as a scale and to answer to the 200 feet from H to I: place the plane table mounted on its stand at the piquet I, and its point L above the piquet I in such a manner that it shall be towards the river, and its line L K on the line I H between the stations: then place the rule against the pin L, and bone the point A by the rule, and draw on the plane table along the side of the rule the line L M, which as well as the others must have its name written against it: keep the rule against the pin and turn it towards the point B, and draw along the rule on the plane table L N, and continue in succession to turn the rule towards the point C, and draw on the plane table a line L G, and this in continuation for the sinuosities D, E, F, &c. where piquets must be previously planted, if there were not some objects fixed which would answer the purpose: then taking the plane table from the station I, place it at the piquet H, disposing it in such a manner that when boning by the two pins K, L, the piquet I can be discovered, and place the rule against the pin K, and bone the point A, drawing along the rule on the plane table a line K P, and do the same with the line K Q, K R, and so on for the other sinuosities, D E F, where piquets also must be planted: in this manner all the windings of a sea coast can be traced, by taking up two stations in a boat securely moored or anchored.

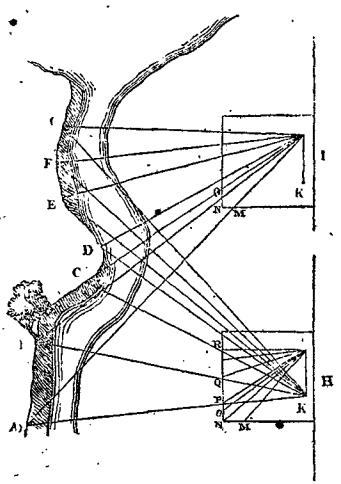


Fig. 1057.

To take the Plan of any Place where entrance can be obtained, as that of the citadel A B C D E F G H I: the angles being distinguishable, plant about the middle of the plot two piquets K and L, at any distance apart, but in such a manner that all the angles from both piquets can be discovered: then draw about the middle of the plane table a station line M N, about a third of its length, which must have two pins at its two extremities: move the plane table on its stand at the piquet K, so that the station point M on the plane table comes exactly above the piquet K, and bone along the two pins, M, N, till the piquet L is seen in the same visual ray: place the rule against the pin M, and bone from it the angles at A, B, C, D, &c., and draw from the pin M, along the rule, the lines M O, M P, M Q, M R, M S, M T, M V, M X, and M Y: then remove the plane table to the station L, and place it in such a manner that the point N on the station line shall be above the piquet L, and that when boning along the station line, M N, the piquet K can be discovered in the same visual ray: then place the rule against the pin N, to bone from this pin all the angles at A, B, C, D, &c. to be taken, and draw on the table the lines 1, 2, 3, 4, &c., remarking where these last lines cut the former, in order to draw lines through these points of intersection, which shall form a figure similar to A B C D E F G H I. A scale may

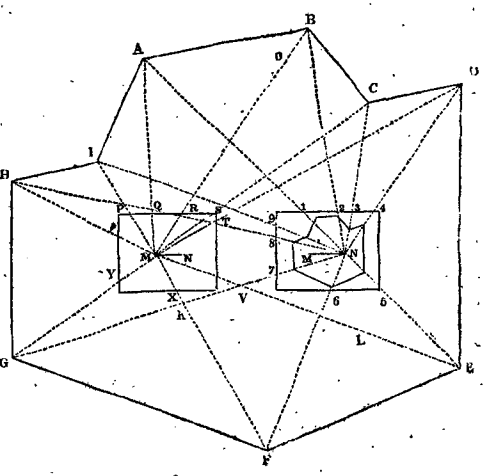


Fig. 1058.

be made by measuring one of the sides on the ground, as E F, in feet, and dividing its corresponding sides on the plane table into as many equal parts.

To take the Plan of a Place where entrance is denied, as that of the town A B C D E F: plant piquets or other marks which may be distinguished, and having measured one of the sides as E F, 236 feet, draw on the plane table a station line G H, which divide into 336 parts, and fix a pin at each extremity of it: place the plane table at the station F, so as to be towards the angle or point G, on the station line precisely. Place the rule against the pin G, and turn it until the angle B is seen; then draw along the rule the line G K; turn the rule towards the point C, and draw the line G L; in the same way bone the line D, and draw the line G M. But for the angle E it is not necessary to bone it, as we have it already laid down. Remove the plane table from F to E, and turn it in such a manner that the point H corresponds rightly on the station line and the side F E, so that by putting the rule against the pin H the angle A may be boned, and draw the line H N; in like manner continue to draw the other lines H O, H P, H Q, to the angles B, C and D, in order to remark where these lines cut those of the first station, on the points R, S, T, V, that by drawing through these points of intersection right lines, we may form with the station line G H a plan R S T V H G similar in all respects with that of the town A B C D E F.

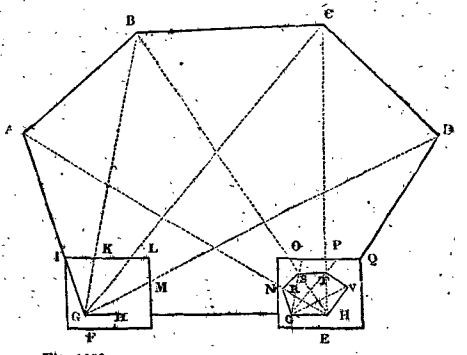


Fig. 1059.

To draw from a given Point a Line parallel to an inaccessible Length, as that of the line B C: plant a piquet at D, the point through which the line is to pass, and another as at E: measure the distance between these two piquets as 50 feet; divide the station line F G on the plane table into 50 parts, to answer to the 50 feet from D to E.

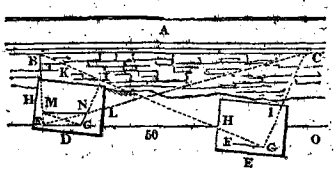


Fig. 1060.

Place the plane table mounted on its foot in such a manner that the point G on the station line shall be above the piquet E, so that when boning by the two pins on the station line G F, the piquet D may be seen in the same visual ray; place the rule against the pin G, in order to bone the two points B and C, which will enable the lines G H and G I to be drawn on the plane table. Then remove the plane table from the station E and place it at D, disposing it in such a manner that when boning by the two pins F and G, we can discover the piquet E, and placing the rule against the pin F, the two points B and C.

Draw the lines F K and F L on the plane table, observing where they cut the lines G H and G I, in the points M and N, in order to draw the line M N, which will be parallel to the inaccessible line B C.

Draw on the ground from the point D a line D O, parallel to this line M N, and the line D O will also be parallel to the line B C.

To measure the Height of accessible Places, as that of the line B C. Plant a piquet D at any distance from the foot of the tower or line B C, as at 40 feet. Divide its station line into 40 parts corresponding with the 40 feet from B to D: dispose then the plane of the table in such a manner as to be quite perpendicular with the horizon, and its station line parallel to it, and the point F on its station line over the piquet D. Place the rule above the pin F, lowering or raising it until we discover by the side which touches the pin the point C; then draw along the rule on the same side as the pin the line F H; from the point E, on the station line, elevate the perpendicular E I, and remark where this perpendicular cuts the line F H on the plane table, as at K: the height E K measured on the station line E F will give a height, to which add that from the point F on the station line to the station point D, and we will have the precise height B C.

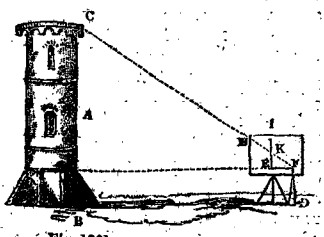


Fig. 1061.

To measure the Heights of inaccessible Places, as that of B C: plant three piquets D, E, F, at any distance convenient, but in such a manner that their summits are in a horizontal line, or that a cord passed through their heads may be level, and looking along it some point G may be established. Measure the distance between the two piquets D, F, as 27 feet, in order to divide on the plane table the station line HI into 27 equal parts, to serve as a scale, and to answer to the 27 feet. Having mounted the plane table on its stand with its plane perpendicular to the horizon, place the point I on the station line I H, precisely against the level of the piquet F, in such a manner that the station line I H should be in the visual ray, which passes above the piquets D, E, F, or along the cord D F. Place the end of the rule against the pin I, lowering or elevating it until you see the point C, and draw along the rule a line I K. Place the plane table perpendicular at the station D, in such a manner that the point H on the station line H I cuts against the head of the piquet D, and that the station line H I shall be in the same line with the heads of the piquets D, E, F. Then place the rule against the pin H, elevating or depressing it until we discover the point C, drawing on the plane table the line H L cutting I K in M.

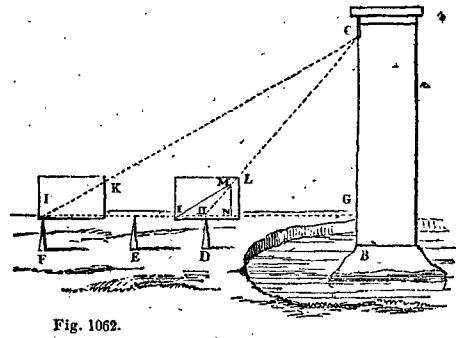


Fig. 1062.

From the point M let fall a perpendicular M N, on the station line H I, which measured on the line H I, which serves as a scale, gives 30 feet, to which 5 is to be added for the height the station line is above the ground, making altogether 35 feet for the height of B C.

To measure the Height of inaccessible Places, when they are at a considerable elevation, as that of the line B C, situated on the slope B D. Plant two piquets E and F in such a manner that their summits are in a right line with the point B. Measure the distance between the two piquets E and F, as 68 feet; divide the station line G H into 68 parts, and place a pin at each extremity of the station line. Place the point H in the station line, precisely over the piquet F, and make the station line G H coincide precisely with the visual ray passing over the heads of the two piquets E, F. Place the rule against the plane of the table until we get the point C, drawing along the rule a line H I. In like manner bone the point B and D, drawing along the side of the rule the lines H K and H L.

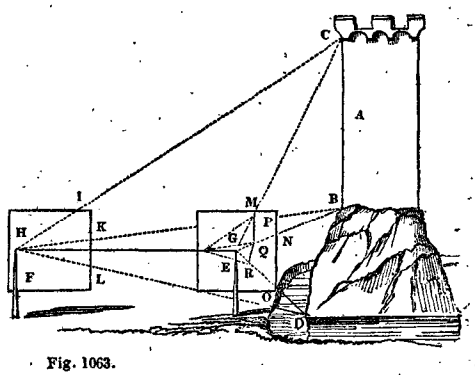


Fig. 1063.

Then transport the plane table to the piquets E, placing the point G on the station line G H, precisely above the head of the piquet E, and make the station line coincide with the visual ray of the two piquets E and F. Place the rule against the pin G, in order to elevate and depress the rule till we discover the point C, drawing along the rule a line G M, and boning also the points B and D; draw the lines G N and G O, and observe where the lines G M of this station cut H I of the first in P, where G N cuts G K in Q, and G O cuts H L in R: draw the right lines P Q and Q R. The line P Q will represent the height B C, and Q R that of the slope B D, so that if we measure P Q and Q R, we shall obtain the entire height.

By the mensuration and protraction of lines and angles are determined the lengths, heights, depths, and distances of objects. Accessible lines are measured by applying to them some certain measure a number of times, as a foot, yard, or chain; but inaccessible lines can only be measured by angles, for taking which, when the plane table is used, the lines are calculated from the principle of similar triangles, or some other geometrical property, without regard to the measure of the angles: this method is not so accurate for

taking angles of elevation or of depression as by the theodolite or quadrant, which latter is divided into degrees, and furnished with a plummet suspended from the centre.

To draw the Map of a Country with the Square Plane Table. — Choose two stations, as A and B, and plant two piquets where the whole of the country it is intended to map may be seen. Then, having measured the base or station line A B, draw on the plane table the line L K, near one of its sides, and placing the plane table mounted on its feet at the station A, turn it in such a manner that the point K of the station line shall be above the point A, with the plane table turned towards the places to be taken, and in such a manner that we discover the piquet B in the visual ray of the two piquets K and L. Place the rule against the pin K, and turn it, boning it towards the places to be taken, and draw the lines K, C, D, E, I; remove the table from A to B, so that this point D may be above the piquet B, and that we can discover the piquet A in the same visual ray with the pins L K; so that by placing the rule against the pin L we can bone the places, observing the lines L, C, D, E, F, in order to note where the lines drawn from the second station cut those from the first; these points will give the just position of the places in the country required to be mapped. But if it be required to find how far these places are from each other, it will only be necessary to measure the distance between the stations A and B, and to divide the station line into the same number of equal parts, and then it will serve for a scale for the whole. If from the two stations A and B we cannot see all the other places, F, G, H, then one or more other stations will be necessary.

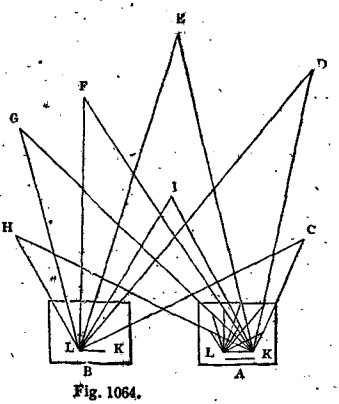


Fig. 1064.

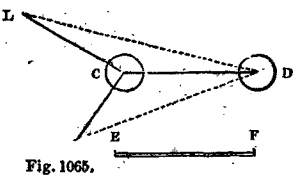


Fig. 1065.

To draw the Map of a Country with the Round Plane Table, which is furnished with cards, each of which has a radius or semi-diameter marked upon it, to answer and serve as station lines, and mounting its stand in some elevated ground, piquets are planted to show the station points, and the distance being measured between them, as in the line A B, 742 feet, serves as a scale. Place the plane table at the piquet A in such a manner that, when boning along its rule or telescope, we can see the piquet B. Then draw along the rule a station line, on which write station from A to B; which being for all the objects whose position we would have, take the card from the table, by turning the screw which holds the alhidade or rule, and place a fresh card on the plane table; then go to the piquet B, placing the centre of the plane table above it, and turn it until we discover by the side of the rule the station A, and draw the station line, writing on it as before, station from B to A; bone from this station B all the objects boned from A, and draw all the lines to the visual rays, writing the name of the object on them as before. Having marked on the cards all the places of the map intended to be laid down, draw about the middle of a sheet of paper the line C D, to serve as a station line, remarking that the map will be large or small in proportion to it; place the centre of the card drawn at the station A on the point C, and make the radius of the card on which is written station from A to B coincide with the line C D; prolong it to infinity on the map to be made by means of rules; draw all the lines marked on the card, and likewise place its centre drawn at the station D over the point D, making its radius coincide with the line C D; prolong on the paper all the lines marked on the card B and the points of intersection, which the lines prolonged from the centre B make with those from the centre A, which will show the positions on the required map. To form a scale, set off the length C D, and divide it into as many feet as were measured from A to B.

The Theodolite has been brought to such perfection, and is so complete an instrument for the taking of large or small surveys, that it has almost superseded all others; formerly they consisted of a whole or half circle, about 10 inches in diameter, divided into 360 degrees, but angles that were vertical and horizontal could not be taken by it at the same time.

The theodolite now in use consists of two circular brass plates, which turn one upon the other, and have a horizontal action by means of an upright axis, which is made of two parts, external and internal; the former is secured to the lower, the latter to the upper plate. The lower plate has its circumference divided into 360 degrees, which are again subdivided, and at the extremities of a diameter of the upper plate are fixed two

verniers; with these horizontal plates and their divisions, all angles in a plane parallel to the horizon are taken in degrees and minutes, and they are adjusted by four parallel plate screws, *g*, set in pairs opposite to each other; these screws are to be moved according as the two spirit levels placed at right angles *a* indicate, and the whole brought to a perfect level. These spirit levels are usually filled with spirits of wine, and are hermetically sealed; the tube is slightly curved, and is placed with its convex side upwards, so that the air bubble, when level, occupies the highest central part. These two plates, called the upper and lower horizontal, are, when adjusted, retained in their position by clamp screws, *h*. On the upper plate rests a frame, on which are the angular receptacles called Y's, into which the telescope is placed; and they are so fixed, that by turning the telescope to observe an object, the horizontal motion is communicated to one or both of the circular plates. The telescope has in the focus of the eye-piece and object-glass three lines formed of very fine wire, one of which is horizontal, the others crossing its middle or central point diagonally, so as to divide the glass into an hexagon. By means of these wires an object or any part of it may be pointed at. From the lower part of this telescope is suspended a spirit level, which being more delicate than those fixed on the vernier plate is used finally to adjust the circular plates, and to bring them to a true horizontal position. The under part of the telescope has a vertical semicircular arc *e*, for the purpose of taking altitudes, the axis of which rests on two points in the frame which supports it, so that when the upper plate is horizontal, the semicircular arc attached to the telescope is in a vertical plane; the angle of inclination being indicated by a fixed index and vernier attached to the upper plate. This vertical arc is adjusted and retained at any required angle by means of a clamp and tangent screw. One side of the arc is divided into degrees and parts, and the other shows the difference between an hypotenuse of 100 units, and the base in right-angled triangles, calculated to degrees of inclination of the hypotenuse, from 0 to 45. To the upper plate is attached a compass, which serves to notice the bearings of the different stations, and also is a check to the angles

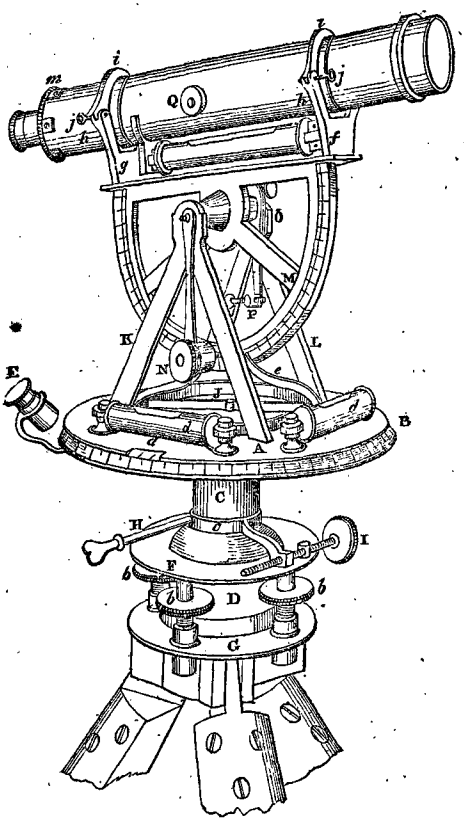


Fig. 1066.

A, B, the horizontal limbs.
A, the vernier plate, which turns.
C, the vertical axis.
D, the ball or socket movement.
d d, spirit levels.
E, a magnifier to read off the degrees.
F & G. Plates are held together by the ball D.
f f, is a screw to adjust the level or line of collimation.
b, *b*, are milled screws to adjust the instrument, and set in level.
g, is a screw to adjust the telescope laterally.
H, a clamping screw, by which means the collar *c* may be tightened to the axis C, and kept from moving.
J, the magnet box.
I, is a slow-motion screw, by which the instrument is moved more exactly than could be done by the hand.
i, *i*, clips, to reverse the telescope by screws *j*, *j*.
K & L are frames into which the pivots are placed, on which the vertical arc M is turned round, and on which the telescope is fixed.
N is a microscope for reading off the degrees.
O is a clamp screw.
P a slow-motion screw, by which the vertical arc and telescope are moved.
Q, a milled screw for moving the object-glass of the telescope.

taken. This instrument, by means of a screw, is fixed on three legs; beneath the centre of the staff head is a hook, to which is attached a plummet, that very much aids the observer in placing the instrument in a horizontal position.

To adjust the theodolite properly is highly important, and the first point to be attended to is, to draw out the tube of the eye-piece till the cross wires are clearly and distinctly seen: the next adjustment is that of the line of *collimation*, the term given to the line passing through the point of intersection of the cross wires, fixed in the focus of the object and eye-glasses, and the centre of those glasses; this, when properly adjusted, should coincide with the axes of the cylindrical rings, in which the telescope turns; this is performed by making the cross wires coincide with a well-defined part of some object in the distance, and turning the telescope half round till the level is at the top; when on looking through it, the same point should be covered by the centre of the wires, which, if it is not, must be acquired by moving the centre half the amount of the deviation, by means of the diaphragm screws, and correcting the other half by elevating or depressing the telescope: when the wires and the object remain perfect in both positions of the telescope, the line of collimation in altitude or depression is correct. This process must also be resorted to, to adjust the line of collimation in the vertical plane. After this, the level attached to the telescope is fixed in a position parallel to the rectified line of collimation, or longitudinal axis of the telescope: to effect this, open the clips that retain the telescope, and bring the vertical arc at or near zero; then turning the tangent screw, bring the air-bubble of the level to the centre of the tube; then reverse the telescope, and if the bubble does not return to the middle, bring it there, one half by turning the screw placed at one end of the tube, to elevate or depress that end of the level, and the other half by the tangent screw that acts on the vertical arc. The circular plates must also be adjusted until they are perfectly horizontal, as any deviation would produce in the measurement of an angle a proportionate error. The bubble of the level under the telescope must be brought to the middle of the tube by the tangent screw of the vertical arc; then turn the upper plate 180 degrees from its former position. Should the bubble not return to the middle, half the difference is to be corrected by the parallel plate screws, and half by elevating or depressing the telescope by means of the tangent screw: this operation is repeated over the other pair of parallel plate screws, until the air bubble of the spirit level attached to the telescope remains permanently in the centre of the tube, in whatever position it is turned. The two small levels on the vernier plate are then to be adjusted by the screws adapted for the purpose. The vernier of the vertical arc is next to be looked to, and should point to zero after all the other adjustments are effected, and any deviation from that point must be rectified by the screws which are attached to it: should the deviations, however, be small, note the amount, and apply it by adding or subtracting from each vertical angle observed. This deviation may be readily discovered by repeating the observation of the altitude or depression in the reversed positions both of the telescope and vernier plates; the two readings having equal and opposite errors, half their difference will be the index errors. When the theodolite has been thoroughly and properly adjusted, it is placed exactly over the station from whence the angles are to be taken; and this is done by observing the direction of the plumb line which is suspended to it: it is then set level by the parallel plate screws bringing the telescope with the vertical arc clamped at zero over each pair alternately. Clamp the lower horizontal limb in any position, and direct the telescope to the object, moving it until the cross wires correspond with it; then clamp the upper limb, and by the tangent screw make the intersection of the wires exactly bisect the object; then read off the two verniers, noting the degrees, minutes, and seconds of both, and take the mean of the two observations. Then release the upper plate, and move it round, until the telescope is directed to the second object, whose angle is required, from the first already observed, and by the clamp and tangent screws make the cross wires bisect the object. Then read off the verniers, and the difference between their mean and the mean of the first reading will be the angle required.

To measure angles of elevation or depression, unclamp the vertical arc, and direct the intersection of the cross wires of the telescope to the object: note the reading of the vertical arc, and repeat the operation with the telescope turned half round in its Y's with the level uppermost; the mean of the two readings will correct the error in the line of collimation. The magnetic bearing of an object is taken by simply reading the angle made by the needle with the common compass, which is ordinarily attached to the theodolite, and usually four or five inches in diameter: the angle cannot be obtained with any truth nearer than by degrees. The telescope shows the objects seen through it in an inverted position; the reason for this inversion is that objects are seen more clearly by the omission of some of the glasses: a second eye-piece is usually provided, which, when applied, shows the objects in their true and natural position.

The Circumferenter is sometimes used where great accuracy is not required in the survey: it is a simple instrument, and consists of a flat bar of brass, B B, about 15 inches in length,

with sights, C, C, at its opposite ends, and two narrow slits *b*, *c* for observations; in the middle of the bar is a circular brass box, A, containing a magnetic needle, and covered with glass. The ends of the needle play over a brass circle, *g*, which is divided into 360 equal degrees, in such a manner that the two numbers of 90° are at right angles to the lines drawn through the sights. This instrument is usually supported on a staff or tripod, E, and when firmly fixed in the ground it can be turned in any direction by means of its socket joint. When the magnetic needle is well balanced, and moves freely in its horizontal position, the sight can be turned towards the object to be surveyed, and the needle will retain its position of due north and south; consequently the number of degrees which the angle contains, after moving from one object to another, can be counted off. The length of the magnetic needle increases the accuracy of the circumferenter, for if made too small it will be apt to follow the motion of the instrument when turned round.

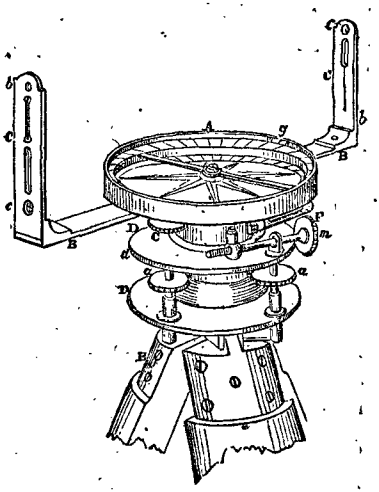


Fig. 1067.

This instrument is chiefly used in mines and coalpits, and sometimes has a spirit level attached to it; *a a* are screws to adjust and turn it round, which is performed by moving the vertical screws at *m*; F is a spirit level; but by the free play of the needle it may be generally ascertained whether the circumferenter is nearly or perfectly level. When this is the case, by clamping the ball and socket joint tight, and turning the sights to the respective objects, the measurement in degrees of the angle made may be relied upon. The needle should not be suffered to play longer than is necessary, but be lifted off its centre, otherwise the delicate point upon which it turns would soon be destroyed. This instrument usually has the east and west marked contrary to their true positions, in order that by the reading off the needle, the actual direction of the line is shown.

The Surveying Cross, employed for establishing perpendicular lines, is a better arrangement than the cross staff, being more carefully made; it consists of four sights, fixed at right angles upon a brass cross, which can be screwed to a tripod or single staff; by placing it with reference to a given line, perpendiculars can easily be traced on the ground or set out.

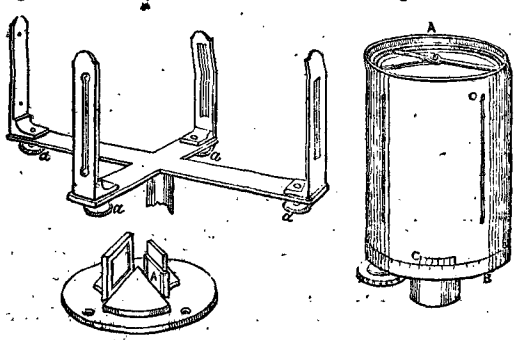


Fig. 1068.

A Circular Box of brass, called the *optical square*, is a more convenient instrument for the same purpose; this contains the two principal glasses of the sextant, viz. the index and horizon glasses, fixed at an angle of 45°; so that viewing an object by direct vision, any other forming a right angle with it at the place of the observer will be seen by reflection to coincide with the object viewed. Placing the instrument in such a position as to look through any given line, we are enabled to direct a station staff to be placed perpendicular to the given line. There are several varieties of this instrument, some of which are fitted for the pocket, and extremely useful to the surveyor.

Prismatic Compass is a similar instrument, but differs from the circumferenter, by having a floating card attached to the needle graduated to 15′ of a degree; but angles cannot be taken with it of less than half a degree: these graduations commence at the north point, and are numbered 5°, 10°, 20°, &c. round the circle up to 360°. A sight

vane is fixed perpendicularly with a fine wire stretched across it, opposite to which is a prism: on applying the eye to the latter, and bisecting any object with the wire in the sight vane, the division on the card coinciding with the thread, and reflected to the eye of the observer, will show the angle formed by the object with the meridian. The instrument must be carefully used when the observation is made, and the card must have free play on its centre, otherwise the results will not be true: each angle as taken should be registered down, which is more simple than first taking one object at 15, and others at 20, 30, and so on, where one is to be subtracted from the other before the angles between any two given points can be ascertained.

The Box or Pocket Sextant is used for laying out angles, and for filling in the details of a survey, where the theodolite is employed in setting out the long lines, and laying out the larger triangles: it is usually divided to 140° on a silver plate, although a greater angle than 110° should not be taken with it: to the sight is attached a small telescope, which often requires time to arrange, and is inconvenient. To take plain sights, there is an aperture opposite the half-silvered or horizon-glass, which answers the purpose better. When an observation is made, take the sextant in the right hand, and apply the eye to the small aperture, looking through the unsilvered part of the horizon-glass to some object or station marked on the line. Then with the left hand, turn the screw which carries the silver glass, until it reflects the object, the angle of which is to be ascertained; when these two objects are, as it were, in conjunction, viz. the object viewed direct through the unsilvered glass, and the reflected object appearing as one, the desired angle will be given. The index or vernier being placed at zero, before the screw, which turns the silver glass is moved, the object viewed direct and by reflection being the same, is a proof that the instrument is correct: should this not be the case, the defect of the instrument must be set right by means of two screws, one in the upper part, over the horizon-glass, and the other at the side of it; these screws must be turned until the object viewed direct and reflected appear, as they really are, one, the vernier standing at zero. There is attached to the vernier a small magnifying glass, which enables the angle when required to be read off.

The Sextant in maritime surveys is of great service, and in all situations where the theodolite cannot be placed on a firm footing, or where the angular distance between two bodies in motion is required, it is of the greatest utility, and almost the only instrument used at sea for taking the altitudes of objects, or the angles they make with one another: when employed it is taken in the right hand, and its face placed in the plane of the two objects, the angular distance of which is required: when the altitude of an object is required, the instrument is held vertically, and when oblique angles are to be measured, in an oblique plane.

The sextant is a modification of the quadrant, and seems to have been the invention of Newton: the principle of its construction may be thus described. Let A, B, be two mirrors moving on axes, parallel to each other, the second mirror, B, being half silvered, so that it admits the passage of rays of light through half its area. Suppose a ray of light to pass from the object C, and reflected on the mirror at A, and after a second reflection from the half-silvered glass B, enter the eye at E. Also let a second object D be seen by direct vision through the half-silvered glass B: it is required the angle subtended at the eye E by the objects C and D. Produce the plane of the mirrors until they intersect in F: the angle A F B is equal to half the angle C E D. For producing A B to G, we have G B E = to B A C + A E B. Then, as the angle of incidence is equal to the angle of reflection,

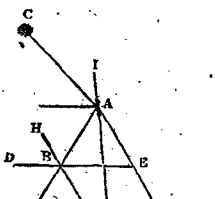


Fig. 1069.

$$H B A = F B E = G B F: \text{ therefore}$$
$$G B E = 2\ G B F = B A E + A E B: \text{ but}$$
$$2\ G B F = 2\ B A F + 2\ A F B: \text{ therefore}$$
$$B A E + A E B = 2\ B A F + 2\ A F B.$$

But because C A I = B A F = F A E,

$$B A E = 2\ B A F:$$

taking equals from equals, we have A E B, or C E D equal to 2 A F B.

When the two mirrors are parallel to each other, and the angle formed equal to zero, the distant object seen by direct vision and its reflected image will seem to coincide.

In constructing the sextant, the arc is graduated to 10 minutes of a degree: these are again subdivided into 10 seconds by the vernier, which moves round an arc, the axis of which is at the centre of the circle: over this centre, and attached to the arm carrying the vernier, is placed a mirror, perpendicular to the plane of the instrument, which moves with the index.

The Index is adjusted by clamp as well as tangent screws: another half-silvered glass is attached to the frame, nearly opposite the first, with its plane perpendicular to the plane of the instrument, and the zero on the limb is so placed that the vernier indicates zero when these two mirrors are in a parallel position to each other: glasses of different tints are

attached to the instrument, for the purpose of taking observations with the sun, and moderating intense light. Before used, the index and horizon glasses must be so adjusted that they are perpendicular to the plane of the instrument, as well as parallel with each other; when the index-division of the vernier is at 0 on the arc, and the optical axis of sight or telescope, parallel to the plane of the instrument.

The Index Glass is adjusted by moving the index to the middle of the limb, and holding the instrument in a horizontal position with the divided limb away from the observer, and the glass to the eye; look obliquely down the glass, so as to see the circular arc, by direct view and by reflection in the glass at the same time, and if they appear to form one continued arc of a circle, the index glass is in adjustment.

The Horizon Glass is in its right position, when by a sweep with the index the reflected image of any object passes over or covers its image when seen directly; any error in this effect may be rectified by turning a screw, placed at the lower end of the frame for this purpose.

The Parallelism of the planes of the two glasses, when the index is at zero, may be readily ascertained, by setting the zero on the index at the zero on the limb; when, on taking an observation, it is observed that the object seen by direct vision and that reflected coincide and appear as one, the glasses are parallel to each other: any deviation is called the index error, which does not often occur in a well-made instrument.

Hadley's Quadrant is often made use of in the same manner for determining the time, latitude and longitude of a place, and is as useful to the land-surveyor as the navigator: its arc is graduated to minutes of a degree, and the vernier at the extremity of the movable limb into seconds, which can be seen by the aid of a magnifier attached.

The telescope at the sides can be moved upwards or downwards by a milled screw beneath it: and it can be so placed that the field of view is bisected by the line that separates the silvered from the unsilvered part on the horizon glass: it is adjusted by sliding the

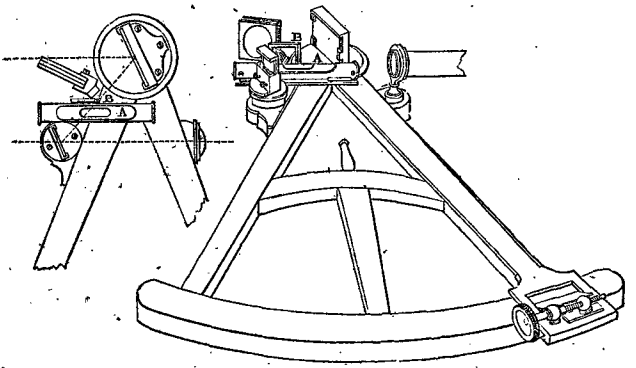


Fig. 1070.

tube at the eye end of the telescope, so as to make the focus suit the eye of the observer. The inverting telescope is furnished with two wires parallel to each other, between which the observations are to be made, the wires being first brought parallel.

A more simple instrument is made on the continent, consisting of two side branches or radii, at right angles, as at A, having the limb E B divided into 90°, and each subdivided into 60′. G F is the telescope, which is rectified by the frames H, H. At P is a joint into which the quadrant is screwed; S is the foot or stem, 5 feet in length, which has a screw at T to secure it.

A M and I K represent bars of brass, on which the instrument traverses: V, V, are four screws by which the stand can be elevated.

When this quadrant is used for taking heights, after the observation is made by the telescope, the angle is ascertained upon the quarter circle by a plummet or bob attached to a fine silk, which works in the box B; this hanging always perpendicularly, the number of degrees is counted up to it.

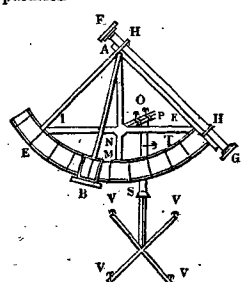


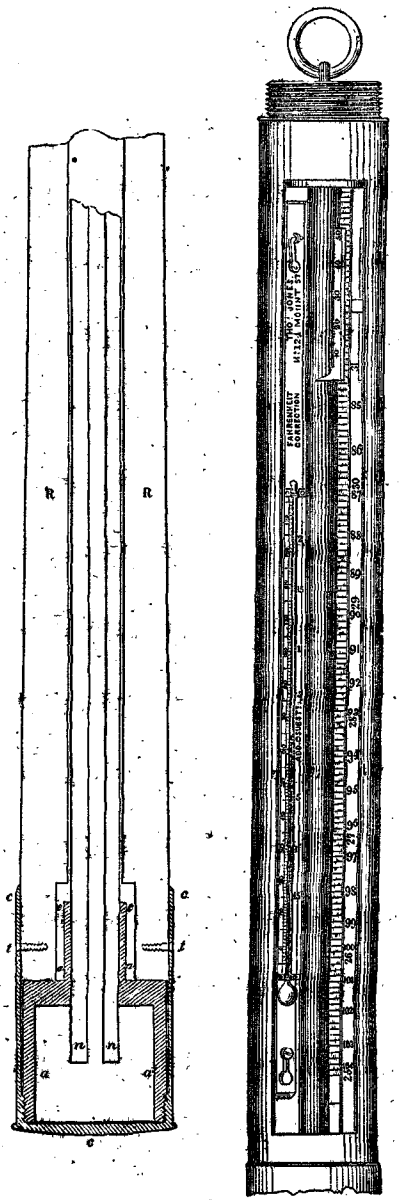
Fig. 1071.

The Barometer is frequently used for measuring the heights of mountains, it being found that the mercurial column invariably depends on, and is in proportion to, the atmospheric

pressure; if we therefore know the law by which the altitudes increase, it is possible to determine the difference between the elevation of two places when their mean barometrical altitude are given; it being an established law of nature, that the pressure of the atmosphere decreases in a geometrical progression, as the height of the place of observation increases in an arithmetical progression. To measure the height of any place, the altitude of the mercury must be measured simultaneously at both the lower and upper stations; the logarithms of these two barometric altitudes being found, the less is to be subtracted from the greater; the difference will be proportional to the difference of the elevation of the two places: to find the real height, this logarithmic difference must be multiplied by a constant number found by previous experiments. Professor Littron, in the Transactions of the Astronomical Society, has given the necessary formulæ and tables, by which great exactness may be arrived at in the measurement of heights; but the system is somewhat complicated, and needs great care, accurate observation, and considerable calculation.

The Chain and Offset Staff are employed alone in land-surveying, or in conjunction with the theodolite, or other instrument for measuring angles: when the chain alone is employed, no other figure can be used than the triangle, and the correctness of the survey depends upon the accuracy with which its sides are measured. The length of the chain must be accurately tested to ensure correctness, before any of the distances are taken; to do this it must be stretched on a level piece of ground, and with an accurate rod it must be carefully measured, and if any error is apparent, it must be rectified equally on both sides of the centre: after this has been done, it may be applied upon a wall, and a permanent mark made upon it, which will serve at any future time to compare it with; long chains enable us to measure with greater accuracy than shorter ones, and angles formed by them are less obtuse.

Gunter's Chain, as it is called, has been found the most convenient where the computation of acres is required, and is in general use by land-surveyors; its length is 66 feet, and it is divided into 100 links: ten of these square chains equal an acre, and as the chain is divided into 100, the contents expressed in chains and links are converted into acres and decimals of an acre, by dividing by 10; an acre being equal to 66 feet multiplied by 66 feet, and then again multiplied by 10, 43,560 feet being equal to 100,000 square links. The rood is one fourth of an acre, and the rod or perch one fortieth of a rood; thus, after reducing the area to square links by cutting off the last five figures, we obtain the acres in



R, R, section.
m, section of glass.
a, box.
c, *t*, brass box.

Fig. 1072.

the remaining figures; the decimal figures cut off are multiplied by 4, to bring them into roods, and the decimal part of the last product multiplied by 40 gives the poles or perches. The chain now in use is of 100 feet, and divided into as many links: whichever chain is adopted for the measurement of distances, it is divided every ten links by brass marks, notched in a manner to distinguish them, and so enable the number of links at any part of the chain to be read off conveniently: ten arrows accompany this chain, and when used two persons are employed, one of whom leads and takes the ten arrows with him: when the chain has been stretched in the proper direction, an arrow is stuck in the ground where the chain terminates; and these are collected by the follower as he proceeds, and when ten have been taken up, they are given to the leader to be used again, care being taken to notice each exchange from the follower to the leader; for when the line is entirely measured, the number of changes added to the number of arrows in the follower's hand, and to the number of links or feet extending from the last arrow put down to the extremity of the line, gives the entire length: the only care to ensure correctness is, that the line so measured is perfectly straight, and that the ends of the chain are made to coincide with the arrows placed in the ground as accurately as possible. The links of the chain being pliable, and united by rings that are not welded, render it extremely liable to get out of order; therefore, it is essential that it should during an extensive measurement be frequently applied to some standard, to examine and test its correctness: this is very important, more particularly so, as it has been advised that no person should be admitted to give evidence in any court of justice with any other than a stamped measure: when the chain is used in wet weather, it often becomes shorter from the collection of particles of dirt getting into the joints or rings, and defective by the bending of the links. When the survey is made with a chain of 100 feet, and it is required to plot it to a scale of five chains to an inch, the scale must be divided into the 330 parts of an inch, there being that number of feet contained in five chains, making 33 divisions, each representing 10. A scale double the length of Gunter's, divided into 100 links, is found both correct and convenient, each link being double the ordinary length.

The Offset Staff is a rod ten links in length, marked at each link by a notch or by brass nails; the follower carries this, and is employed by the surveyor for taking offsets, but where these offsets are considerable, a tape 100 feet in length is the most convenient: they should always be taken at right angles to the main line, and formerly the cross staff was employed; at present, an instrument called the optical square is found the most convenient for this purpose, it is a small circular box about 2 inches in diameter, which makes a right angle with both accuracy and expedition; it has two glasses fixed at an angle of 45° from each other, and one of them acts as a mirror; the other is half silvered, so as to admit direct vision of one object and reflected vision of the other; so placed at right angles to a line passing from the observer to the first object, the image of the second is reflected from the first mirror: the principle is, that the angle made by the first and last direction of a ray of light which has suffered two reflections in one plane, is equal to twice the angle of inclination of the reflecting surfaces. With this little instrument right angles may be accurately set out, by the observer simply standing over the given point and looking through it along the line, having some one with a marking rod in the direction where the perpendicular is to be set out, and by motioning him to the right or left, until the rod he holds is seen by reflection to coincide with a staff fixed on the line where the observer is looking; when this is the case the rod is fixed in the ground: a perpendicular line is often set out by the use of the chain only, by measuring on the base line a distance of 40 feet; then at the extremities of this distance measuring as an hypotenuse 50, and as a perpendicular 30; when the sides of a triangle are in the proportions of 30, 40, and 50, it is a right angle, and has the two short sides perpendicular to each other.

To survey a Plot of Ground with the Chain, we are confined to the use of the triangle, it being the only figure the sides of which cannot be altered. The field to be measured is then divided into a series of triangles of as large a description as can well be obtained; much of the judgment of the surveyor is called into play upon the adoption of the triangle, or laying out the sides of the figure, which should approach as nearly as possible that of the equilateral: the sides of the triangles are then measured, also a line from one of the points to the middle of its opposite sides which enables the surveyor to detect any error that may have been committed in the measurement of the three sides: the general combination of these triangles must be laid down so that the largest come as nearly to the boundary of the spot as possible; and when their figure is determined, pickets are placed on the ground at their angles; these are called station points, and are measured to and from, and all the lines connecting them are denominated station lines, which are to be distinguished from the simple offset lines.

The Field Book should commence with a rough sketch made of the land to be plotted, and which should be the result of a careful walk over the ground previous to the measurements being taken: it is ruled into three columns; in the middle one is to be set down

all the distances measured on the station line, at which any mark, offset, or other notice is made: in the right hand column are placed all the measurements of the offsets in that direction, and in the left hand column those on that side of the station line. The middle column represents the station line, and whenever it passes a road or boundary, it must be marked obliquely to denote this deviation. The entries in the field-book are usually commenced at the bottom of the page for convenience, the surveyor keeping his face in the direction of the distant station: wherever fences or other objects, as rivers or streams, are crossed, they must be sketched in the field-book in as accurate a manner as the time will permit; by this much subsequent labour is saved. On commencing the measurement along the station line, the letter corresponding to the starting point is placed at the bottom of the middle column of the field-book, and on each side is written the letters whence the measurement is taken, and at every new distance this is again to be observed.

When the whole of the measurements have been made and entered in the field book, the contents may be ascertained by computing the areas which are enclosed in the measurement of the respective triangles; but it will be first necessary to reduce all lines measured over steep hills to a horizontal plane; should the inclined plane or slope not be very steep, the difference may be rectified by holding the chain horizontal whilst measuring, which may be judged of by the eye; or if the slope be steep, half the length of the chain may be used: when the angle of inclination is 4°, an allowance of 1 in 15 is made, 6° 1 in 9½, in 7° 1 in 8, in 10° 1 in 6, and in 20° 1 in 2¾, or 6 feet for every 100 feet; this, however, may be readily ascertained by careful observation. The angles of inclination should always be observed where perfect accuracy is required, and the proper deductions made when the work is laid down or mapped.

Parish surveying.—Where it is required to obtain the area of the whole by some other means than that of adding together the contents of each enclosure, it seems the simplest method to commence by measuring two straight lines through the entire length and breadth of the parish; to connect the ends of these by other measured lines, and upon them as base lines to construct triangles and measure the offsets. The contents of the entire parish may then be ascertained by calculation; the lines measured to accomplish this should be shown on the plan when finished. These main lines should pass over the most remarkable objects, as the church, the mill, the manor house, and their extremities should be marked by a stone or permanent boundary, that may be referred to on all future occasions. This boundary should be shown on the plan by a dotted line, and when a fence constitutes the boundary, the dotted line should be shown on both sides of it: when this boundary passes through a field, the whole field should be shown. The plan should be drawn to a scale of 3 chains to 1 inch, and the north point should always be at the top of the plan.

To measure the base or principal line, which should be the longest that can be obtained, the theodolite is placed at one extremity, and the angle formed by this line with the magnetic meridian must be first accurately obtained: then all the angles of the several prominent objects; at this spot a pole must be placed perpendicularly, and proceeding along the line, the roads, rivers, &c., must be noted as they are crossed, and all convenient offsets should be taken. Poles should be set up at all the prominent stations, which serve to guide the measurement and insure its being in a straight line: these must be constantly boned, or the true course will be departed from.

Where objects occur which are not accessible, angles must be taken with the theodolite, either to the right or left of the line, exactly at 60°, and then measured out to any length until clear of the obstruction: another angle of 60° must be taken and measured, the same distance as before; these forming two sides and angles of an equilateral triangle, the remaining angle and side will be the same, and the distance, if measured through, will be found to agree.

After measuring up to the other extremity of the base line, the theodolite is placed upon it, and the angle of one of the side lines taken with considerable accuracy; these side lines must then be measured, and the theodolite placed at their extremities, so as to measure the angles made with its transverse lines: and so proceed with the respective lines and angles, till the whole is completed. From the extremities of the two principal lines, measure the distances one from the other, or the length of these tie lines, taking at the same time their angles very accurately. These angles and tie lines form four principal stations or boundary points to the parish, and should be marked permanently. The whole of the outline between these four stations or the natural boundary may be surveyed, and afterwards the portions within for the filling up. The sextant is employed usefully in taking all the interior angles, and uniting them with the main lines which run through and traverse the parish: these two instruments are now the only ones employed.

To compute the area or contents of the parish, the whole should, after it is mapped, be thrown into triangles, and each enclosure treated in a similar manner: but the most correct method would be to divide it into squares of about a chain, by which means the small parcels would have their quantities easily ascertained.

Subterranean Surveying is performed with the miner's compass, which for observations of horizontal angles is by no means sufficiently accurate. The circumferenter or half theodolite is more so, and may be used with greater certainty, though the common theodolite should always be preferred: it is often of more importance to have an accurate plan of the works in a mine, than of the land above it. The surveys of pits or mines being not only made to direct the working, but for the sinking of shafts, ventilation, or for the raising the produce, after the situation of the shafts are determined on above ground, the workings below must be either set out on the surface, or the survey must take place beneath. To adapt the theodolite to mining observations, the stand on which it rests should be so formed, that it can be readily disengaged.

The survey is commenced with the assistance of two men, who carry the chain, and two others the lamps, one of which is placed at the starting point from whence the measurement is to commence, and the theodolite is advanced in the direction of the line, as far as it is possible to obtain a sight of the lamp at the point advanced from. The vernier of the theodolite being fixed at zero, the telescope is directed towards the light, and the angle of inclination noted down, another lamp is advanced along the line and the same observations taken: the distances are then carefully measured from one station to the other, as practised in roadway surveying: all underground surveys should be made to agree with those taken on the surface, which may be readily done by comparing the adits and shafts, both as to their distances and bearings to each other.

Care must be taken to notice whether the needle is affected when the theodolite is used, which is sometimes the case; when the instrument is elevated 2 or 3 feet above the tram plates of a railway, there does not seem to be any sensible attraction between them and the needle.

Maritime Surveying, comprises the laying down charts with accurate representations of the coasts and harbours, and is one of the most important applications of the science, as it enables the mariner to pursue his voyage and return to his port without encountering those dangers which beset him in the shape of rocks and shoals, shallows and flats. The first thing to be performed for the construction of a map or chart is to refer to some fixed points on the shore of the coast to be laid down; these are ascertained with great precision by means of a trigometrical survey on shore.

Tide Gauges are erected in well-chosen localities in a vertical position, and divided into feet and tenths: the zero point of each gauge corresponds with a bench mark permanently fixed, so that should any be displaced by the violence of the sea, they can, by means of a spirit level, be refitted in their original position.

These gauges serve after a series of observations to give the lowest point of the lowest tide at full and change of the moon, and to the level of this lowest point the depths of all the soundings are referred: they serve also to show the rise and fall of the tide, by which means all the registered soundings are reduced to the lowest level: this is very essential, as it is not practicable to take all the soundings over an extensive bay at the precise time of low water: near the shore these observations may be made with reference to some permanent marks made on the walls of the quays.

A second gauge is placed further out at sea, so that when the tide has left the first, the second may be observed. Then the zero division of the first gauge must be compared, by means of the spirit level, with some division of the second; and this, as well as each successive gauge, must be denoted by some number or letter, and entries made to record the time of changing from one gauge to another. A situation should be selected where the base of the tide gauge is not left dry at low water.

When an observation is to be made, a person with a well-regulated watch is stationed at each tide gauge for the purpose of registering the height at every quarter of an hour or other stated intervals. A meridian line is marked upon each station, so that the observer may regulate his watch by the course of the sun.

The time of high water at the full and change of the moon should be carefully marked on the tide gauge, and this time may be either mean or apparent, but whichever is selected must be noted; the instant to be registered is that when the surface of the water is the highest, but if the water is perfectly calm, its change when near the highest point is slow, and it almost seems stationary for some moments. To prevent the effect of waves rendering the surface uncertain, an upright pipe is sometimes fixed by the side of the gauge in such a situation that at low tide the water only reaches the lower part: the bottom of the pipe must be stopped, and a number of small holes drilled in it near the bottom about a quarter of an inch in diameter. A float is then placed on the pipe which carries a light rod, and by means of feet and inches marked on it, the rise of the tide can easily be read off.

In narrow channels or at the mouths of rivers, a great many gauges are requisite, and no precise number can be mentioned, as that must depend altogether upon circumstances. Churches, lighthouses, are then made use of on land, to serve as vertices to the triangles about to be laid down, and it is usual to place signals upon them; and those which serve to be viewed from the sea are painted white, when the ground falls behind them, but of a

darker colour, when they are projected against the sky. All this being arranged, the operations for the survey may commence at sea. There are three methods adopted for determining, by reference to fixed points on shore, the locality of any station at sea. The first consists in observing by means of the compass the bearing of two or more points on shore, by which means the position of the observer is determined when the position and bearings of the points on shore are given with respect to each other. Suppose A B to be two objects on shore, and S the position of the observer, from which the angles and meridian is observed. In the triangle A S N the angles at S and N are given, consequently the angle at A is known; in the same manner the angle at B is known. Then on the side A B, and the adjacent angles A and B being given, the point S may be found: with the compass, however, the angles cannot be determined nearer than within one or two degrees; when two compasses are employed, one at a height of 2 or 3 feet above the other, the mean between the two observations made will perhaps approach the truth.

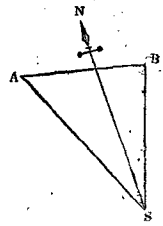


Fig. 1073.

The second method is by observing at the same period of time from two or more stations on shore the bearing of the observer at sea, and this is only to be done by means of well preconcerted signals.

The third method consists in measuring from the boat by means of the sextant the angles subtended by three or more objects on shore, the positions of which are given; from these data the position of the observer is determined.

An instrument called a *Station Pointer* is used to insure greater accuracy in taking angles; this is formed of three rules which revolve on a common centre, in such a manner that two triangles can be set out with it; the middle rule is double, and has a fine wire stretched along its openings; the others have also a fine wire, which is stretched from end to end, and so adjusted that all the three wires tend to the centre of the instrument; in the centre is an opening through which a steel pin may be passed: attached to the middle limb are two verniers, with arcs of about 100° each, and when all the limbs are closed, the verniers mark zero, and as the limbs are opened the verniers mark on the corresponding arcs the angles they respectively form: the angles subtended by three stations on the shore at the place of the observer at sea are the measures to which the verniers are to be set; and when so set the instrument is laid on the plan, and moved till the three wires pass through the three stations; the centre of the instrument then occupies the relative place of the observer, and a dot marked by the steel pin determines the point on the plan: a graduated circle on paper or on glass may serve this purpose as well; by drawing on the upper surface lines diverging from the centre at the given angles, the circle being moved until these radii pass through the stations, the centre of the circle will give the point required. Excepting in a case where the observer is in the circumference of the circle passing through the three stations, the measure of two angles is sufficient to determine his position; it is as well to observe as many angles as possible, and where accuracy is required, the observations of two angles only should never be considered sufficient. The angles are taken with the sextant or the reflecting circle, and measured in the plane of the objects: should this plane be inclined to the horizon, the angles of elevation of each station above the horizon should be observed, to give the necessary data for reducing the hypotenusal to the horizontal angle: when the difference of elevation is great, an ideal vertical line may be drawn from the higher object downwards until it apparently meets the base, and the results will be sufficiently near the truth; as in the height of a mountain, the line B C may be dropped. It is not usual to apply a telescope to the sextant, as the objects are brought readily into the field of the mirrors by the unassisted eye; and time is a great object, and perhaps the most important of all in making the observations. Sea-water destroying the silver on glass, metallic reflectors are generally substituted.

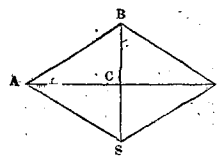


Fig. 1074.

Sounding Lines, to ascertain the depths, are formed of strong pliable cord or lead line, divided into feet by different coloured pieces of cloth or other marks; the lead fastened at the extremity is like the frustum of a cone, with its base so hollowed out that grease may be introduced into it, which serves, when let down upon sand or mud, to show the nature of the bed: lines of different lengths and strength are used, and leads differing in weight according to the depth of the water to be sounded; these lines are liable to sudden changes, and must be constantly compared with some known standard; deep soundings must be taken when the boat is still, and the depth measured in a vertical position: in shallow water sounding rods are substituted, and where hard rocks occur they are perhaps more convenient. *Sunken rocks, reefs, and shallows*, require great accuracy in the survey, and it is necessary to cast anchor, in order to get the angles and their measurement with more certainty: when the shoal or reef is so far out at sea, that only two objects on shore can be seen, an assistant boat must be moored

between the observer and the coast, in such a position that one additional station can be seen from it: at the time of a given signal, angles are observed from the assistant boat to three objects on shore, and to the distant boat; and from the latter, angles at the same time measured to the two stations on shore, and to the assistant boat: suppose D to be the distant station, from whence A and B can be seen, and E the position of the assistant boat from whence A, B, and C can be seen; then at the same moment of time, the angles are observed from E and from D; their mean show the position of D; for the point E is fixed in position by the observed angles C E A, A E B, and it becomes therefore a fixed station with reference to D, from which two angles are observed to three stations fixed in position. Breakers and currents must also be observed at that time when the tide is favourable, or when a perfect calm allows them to be recognised.

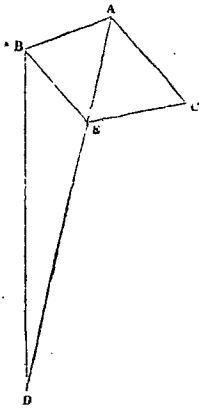


Fig. 1075.

To reduce soundings after they have been taken consists in deducting from the depths, as noted down, proportionate quantities varying with the time, so that all may agree with the lowest level of the tide; the whole are then written on the chart in fathoms and quarter fathoms.

Maritime Surveying without the aid of Triangulation on Shore, is not in its results so accurate as that where they can be adopted; but where free access to a country is not attainable, this method is resorted to as the nearest approaching to the excellence of the first: instead of commencing with the measurement of a short base, and a series of triangles spread over a great area, a much longer base is established; sometimes one of 50 miles or more: upon this all the observations are made, and the details laid down as quickly as they are taken, and all errors corrected during the progress of the work. On the choice of direction for this base line much of the success depends: elevated land, or some mountain or conspicuous object, should terminate each extremity; and the more numerous the intermediate objects that can be seen from the ends of this base line, the greater will be the correctness of the survey. The latitude and longitude of the first station being taken and determined by astronomical observations, and the bearing of the several objects by the compass, the same is to be done at the chief stations along the line selected for the base. The stations are determined by the chronometer and measurement of the rate of sailing; from them the observations are made which are to be laid down on the chart: the distance between the primary stations, whose latitudes and longitudes have been determined, is obtained by supposing P to represent the pole of the earth: the angle P is known by the difference of longitude between the two stations B and A; the sides P A and P B are also given, being the respective co-latitudes of the two stations. In the spherical triangle A B P are two sides and the contained angle, from which we may obtain the length of the opposite side A B: a line joining any two of these stations is the arc of a circle on the surface of the earth, and must therefore be reduced to its chord, which is equal to twice the sine of half the arc. When a survey of a coast is made at night, and intersections cannot be obtained, observation must be taken within a few miles from the shore by anchoring the vessel at one or more intermediate stations: the position of the vessel is determined by a careful observation of the angles subtended between the sun and primary stations, noting the time also when the observation is made: the time gives the sun's azimuth, and from it is deduced the azimuth of the two primary stations from the vessel; those intermediate are obtained by the intersection of their lines of direction as observed at the different stations. The details and soundings are then to be taken, with the filling-in as it can be obtained; by this means a very accurate map may be laid down: it is often necessary to make a survey of the coast when a ship is under sail, and although the system adopted may vary in its details, the general principles are the same. The angular distances between prominent points of land as observed from the vessel, should be taken when at anchor, and the outline of the coast sketched: astronomical observations must be made at the same time to determine the position of the vessel, and the bearing by the compass noted: continuing a series of such observations in sailing from one point to another, and having special care not to lose sight of the points to which angles have been observed, as this would lead to confusion and great difficulty when the whole is to be laid down on paper. A reckoning of the ship's rate of sailing must be carefully noted by the log line; though much reliance cannot be placed upon it, it may help, in some degree, to check any error arising from the astronomical observations: when sailing, care must be paid that the vessel has all its bearings

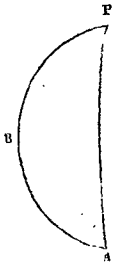


Fig. 1076.

accurately noted when she changes her course; then, proceeding in the same manner as already described, the soundings and remarks will enable a tolerably correct sketch of the coast to be made. Distances are sometimes measured by sound, which travels at the rate of 1090 feet per second of time; a chronometer will enable a distance of several miles to be determined with considerable accuracy: the time between the flash and the report of a gun being found, the distance may be calculated by the above rule.

Trigonometrical Surveying.—The survey of a country, when carried on upon an extensive scale, has much of the labour of admeasurement abridged, by merely applying the rods or chains to a base line, and calculating the other distances by triangles; the difficulties which attend the operations of a trigonometrical survey of a country must not, however, be underrated, particularly when the object is to determine the distances as well as the positions of places with the greatest precision. Upwards of one million sterling had been granted in the year 1841 by the Houses of Parliament at several times to carry out the Ordnance surveys of the United Kingdom. A general survey seems to have been commenced in the year 1783, in consequence of an application made by the French government to Mr. Fox, then Secretary of State of the Foreign Department, to carry a chain of triangles from London to Dover, which could be connected with those of the French arc of the meridian already extended to Dunkirk; so that by actual measurement the relative positions of the observatories at Paris and Greenwich might be determined. This application was laid before the Royal Society by Cassini de Thiery, and the great advantages which would result from it were highly appreciated by that body. The English government, in consequence, employed General Roy for the operation, who had already commenced a survey of the neighbourhood of London, for the express purpose of connecting the private observatories with that of Greenwich: as early as 1747, a survey of the Highlands of Scotland was undertaken by this officer, which was considerably advanced by the end of the year 1755. To obtain an accurate base line, so that by its measurement all the other triangles constructed on it should be computed, was the first part of the operation: and for this purpose General Roy selected a line on Hounslow Heath, in consequence of the level surface the ground presented, and its proximity to the Royal Observatory at Greenwich. The terminal points of this base line were marked by wooden pipes sunk in the ground, and the measurement was commenced in June, 1784.

The first mode was with deal rods, which had been employed previously in other countries: but it was soon evident that from the alternations of dryness and humidity, they were subject to sudden and irregular changes, and by no means fit for a purpose where such great precision was necessary. These rods were cut out of an old mast of Riga timber, and made 20 feet 3 inches in length, tipped with bell-metal, to prevent their ends from being injured; they were 2 inches in depth, and $1\frac{1}{4}$ inch broad, and rendered inflexible to a certain degree by trussing; when, however, applied to the standard during the measurement, they were found each to have increased the fifteenth part of an inch, and were consequently laid aside: glass rods were then substituted, as tubes of this metal could be easily procured of the length required. Three hollow tubes, 20 feet in length and 1 inch in diameter, perfectly straight, were provided, and converted into measuring rods by Ramsden; they were placed in cases made fast in the middle, and braced at several other points, to prevent their shaking or bending, but not their free expansion and contraction; the ends of these rods were smoothly ground, at right angles to the axis of the tube; one end had a fixed metal button attached to it, for making the contacts, and the other a movable slider which could be pressed outwards by a slender spring, and against which the fixed extremity of the succeeding rod was placed, and then pressed until a fine line on the slider was brought into exact coincidence with another fine line on the glass rod, when the distance between the two extremities was exactly 20 feet. To ascertain precisely the expansion to which these glass rods were subject, they were submitted to a microscopic pyrometer, when their expansion could be ascertained for every degree of temperature from 32° to 212° of Fahrenheit's thermometer.

After much calculation upon the expansion and contraction of the rods they were applied to the base line, which was not over perfectly level ground; consequently it became necessary to divide the whole distance into inclined lines, each containing about 600 feet. This was done by placing the rods exactly in straight lines, stretching from one extremity of the hypotenuse to the other, and then determining the relative heights of the two extremities by means of the spirit level, for the purpose of reducing the horizon; the cases containing the glass rods being throughout supported upon trestles, which were about 30 inches in height. After the measurement was completed, its true length was reduced to that of the level of the sea, the mean semi-diameter of the earth being estimated at 3,492,915 fathoms: infinite pains were evidently taken throughout the whole operation, and the means employed seem to have been the best that could be suggested.

The true length of the base was fixed at 27404·0137 feet, but when the Ordnance survey was commenced in 1791, it was thought necessary to remeasure this line, from an idea that as the ends of the two consecutive rods, having been made to rest on the same trestle, when one was removed the trestle would have a tendency to incline forward, which

would shorten to a certain degree the measurement, or the flexure of the rods would produce the same effects. Two steel chains, each 100 feet in length, and containing forty links, made by Ramsden, were selected to remeasure the line: the links were in the form of a parallelogram, of $\frac{1}{2}$ inch square and 30 inches in length. When used, they were strained over five boxes placed at equal distances upon bricks, and stretched in a straight line by weights of 56 pounds: to bring the extremities of the two chains together over the same point, they were supported at each end by an upright piece of wood or post; that of the preceding end had attached to it a pulley over which passed the rope which stretched the chain, whilst to the end that followed was applied a screw apparatus, by which the chain could be drawn back against the weight: another upright or post at each end, not connected with the others or with the chain, supported a scale.

The chain being placed, the scale at the preceding end was moved by means of screws, until one of its divisions exactly agreed with the mark on the handle of the chain: the scale remaining in its place, the chain was then carried forward, and again adjusted by the screw scale in a similar manner: after 38 of these chains had been used, one in consequence of the links being bent was laid aside, and the base line was measured by the other; the one laid aside being repaired, was retained as a standard. Experiments out of number were made previously, to ascertain the rate of expansion, and a thermometer was placed at each of the five boxes when the measurement was taken, in order to insure accuracy; the chains, after the measurement, were again compared, when it was found that that which had been used had lengthened through the rubbing of the joints ·0373 of an inch.

The length of the base line was by means of the chains found to be 27404·3155 feet, being about $2\frac{3}{4}$ inches more than that measured with the glass rods. The mean of the two results, 27404·2 feet, was then assumed for all the future calculations. Rods seem, however, in general, to have a preference over the chain, where great accuracy is required, as they cannot be considered so flexible, nor are they so likely to increase in length, as the chains when slightly strained may do at the joints: great care must be taken at the commencement of such an operation, in ascertaining the exact length of the foot, to be marked on those measuring rods or chains, and some standard should be applied to for the purpose. Such a standard is now adopted as constitutes the yard at 36·000659 inches, the length of the pendulum vibrating seconds being taken at 39·13929 inches; this is called the imperial measure, and as it was supposed to be a correct and unalterable quantity, it was prescribed by Act of Parliament that the length of the standard yard should be restored by reference to the length of a pendulum, should accident occur to injure the legal standard deposited in the House of Commons.

In Ireland another method was adopted to measure the base line set out on the plains of Magellan, which is between 7 and 8 miles in length, and where the greatest possible error is not supposed to exceed 2 inches. Two bars, each 10 feet long, one of brass, the other of iron, were placed parallel to each other, and riveted at their centres, it having been previously ascertained by experiment that they expanded or contracted in the proportion of three to five; some nonconducting substance was spread over the brass bar, which equalised the two metals in their susceptibility as to change of temperature: a tongue of iron, with a minute dot of platina, was fixed across each extremity of these two combined bars, and this tongue had the dots so placed that under every change of contraction or expansion they remained at the constant distance of 10 feet. The tongues were perpendicular to the rods, at the temperature of 60 degrees of Fahrenheit, and the expansion of the two bars of brass and iron taking place from their common centre, as the inclination of the tongues became changed, the platinum dots remained unalterably fixed at the exact distance of 10 feet. When the base line is accurately taken, it should be reduced to its proper measure at the level of the sea, and as this is constantly changing, some elevation must be established that can be referred to, and that made use of by the Ordnance surveyors is low water mark.

Suppose R = to the radius of the earth at the level of the sea; $R+h$ equal to the radius at the level of the measured base; A = to the measured base A B, and a = to the reduced base $a\,b$.

Then, as similar arcs are in the same ratio as their radii, we have $R+h : R :: A : a$, and

$$A = \frac{R \cdot A}{R+h}$$

and the difference between the measured and reduced base is

$$A - a = A - \frac{R\,A}{R+h} :$$

reducing both terms to a common denominator:

$$A - a = \frac{A\,R + A\,h - A\,R}{R+h} : \text{ whence}$$

$$A - a = \frac{A\,h}{R+h} = \text{difference required.}$$

The elevation of Hounslow Heath is about 102 feet above the level of the sea, and the

measured base 27405·6677 feet, after due correction made for temperature, &c. The radius R being taken at 7,002,667 yards; the length of this line at the level of the sea is thus found:—

A, the measured base, is equal to - - -	27405·6677 feet
h, the height, - - - - - -	102
R, the radius of the earth, - - - -	21008001

$\frac{27405{\cdot}6677 \times 102}{21008001} = 0{\cdot}133$ feet. Hence the reduced base will be 27405·6677 − 0·133 = 27405·5347 feet.

Before a base is reduced to its length at the level of the sea, it is necessary to consider its horizontal value, as all lines measured over the earth's surface must be treated as concentric, and are more or less inclined to the horizon.

Signals, and their Construction.—When the base has been set out, permanent signals must be established; they should be constructed in a durable manner, and have perfect steadiness.

In ordinary surveys straight poles fixed in trees or firmly in the ground may serve sufficiently for all purposes, and when greater security is required, they may be held in a vertical position by ropes, in the same manner as a ship's mast, and such an arrangement may be easily rendered more lofty by means of an additional mast, and the help of guys and stays. These masts have each a bunting flag, usually either red or white when projected against a dark ground, and green and red when against the sky; sometimes a circular disk of sheet-iron is found a better substitute for the flag, and may be attached to the top of the pole.

The parabolic reflector has been successfully employed in Ireland, and for the illuminating power, a ball of chalk lime was submitted to a stream of oxygen directed through the flame of alcohol; the light was estimated at 83 times the intensity of the brightest part of the flame of an Argand burner of the best construction, supplied with the finest oil. The direction of this light was marked by placing a guiding light at the distance of every 15 miles, which was a 15-inch parabolic reflector illumined by an Argand lamp: by this means the former light, though 66 miles distant, was perceived, larger and brighter than the guiding lights. Plano-convex lenses, 2 or more feet feet in diameter, illumined by an Argand burner, with four concentric wicks, the lens composed of a series of concentric rings reduced in thickness and cemented together at the edges, are often used, and their appearance at a distance of 48 miles is stated to resemble a star of the first magnitude.

Summits of mountains are usually selected for stations, and the signals constructed upon them are built either pyramidically or conical, with a pillar in the centre. The selection of stations depends much upon the nature of the country to be surveyed; they ought to be placed in such positions as to be visible from each other, that the errors of observation may have as little effect as possible on the distances measured: the triangles should be equilateral; the smallest errors are likely to occur when the angle opposite to the measured side is less than a right angle, and the angles adjacent to that angle are nearly equal: in general no angle should be less than 30 degrees, and then the calculated sides in a series of triangles will not be very different from those obtained by actual measurement.

When a great survey is undertaken, the sides of the first triangles should be of greater length than the original measured base, and which is readily accomplished; triangles whose sides were from 70 to 90 miles in length were adopted in Ireland, though in England those whose sides were from 12 to 18 miles were considered preferable.

Calculation of the sides of Triangles.—All the angles and the triangles which are taken in a trigonometrical survey by the theodolite are spherical, as they form a part of the surface of a spheroid: it is evident that as every object used for pointing the telescope of a theodolite has some certain elevation not only above the soil, but above the level of the sea, and as these elevations differ in every instance, a reduction to the horizon at all the measured angles is necessary; but by the construction of the theodolite, this reduction is made by reading off the horizontal angles. Ramsden's large instrument, 3 feet in diameter, was the first by which this spherical excess was observed; it is in all trigonometrical observations small, not exceeding 4 or 5 seconds in the largest triangles employed: if the earth's surface was a plane, the sum of the three angles would be exactly 180°, and the excess above 180° is so far from being a proof of incorrectness in the work, that it is essential to its accuracy, whilst it offers at the same time another proof of the earth's sphericity. The true way to judge of a trigonometrical survey is to consider the net work of triangles as the bases of so many pyramids converging to the centre of the sphere: the theodolite accurately measures the angles included by the planes of these pyramids, and the surface of an imaginary sphere at the level of the sea intersects them in an assemblage of spherical triangles, above whose angles in the radii prolonged, the real stations of the observations are raised by the superficial inequalities of mountain and valley. When the triangles are so large as to make the difference between the chords and their arcs perceptible, the condition of the sphericity must be ascertained, or else, when all the triangles are laid

down, they would occupy a greater area than they ought: the triangles must, therefore, be considered as spherical, and treated as such, when their sides are to be calculated; when angular distances are measured by a theodolite, the plane of the instrument is so adjusted to the horizon that the angle observed is the horizontal angle of the station. The three summits of the triangle so measured are equally distant from the earth's centre, which is not the case when the sextant and repeating circle are used for the purpose of measuring angles. The centre of the theodolite being placed directly under the centre of the signal destroys the necessity of any calculation for reducing the observed angle to the centre of the station.

In all spherical angles the three angles together exceed 180°, by what is called the *spherical excess*, which is proportional to the area of the triangle; A B C, being the angles of a spherical triangle, r the radius of the sphere expressed in feet, $x = 3{\cdot}14159$, the proportion the circumference has to the diameter, and S the number of square feet contained in the area of the triangle; then by trigonometry,

$$S = \frac{A + B + C - 180^\circ}{180^\circ} r^2 x.$$

Let E denote the spherical excess, $= A + B + C - 180^\circ$; then $E = \frac{S \times 180^\circ}{r^2 x}$ in degrees, or $E = \frac{S \times 648000}{r^2 x}$ as expressed in seconds: in any triangle which can be measured on the surface of the earth, S is very small in comparison with r^2, and therefore E is a very small quantity: in practice it seldom exceeds four or five seconds; but in the triangle of a side of 100 miles in length, it would amount to more than thirty or forty: an approximate value of S is sufficient then to compute the value of E with precision; and for this purpose, we must consider the triangle a plane one: let abc be the number of feet in the respective sides opposite to A B C: we shall have for the area $S = \frac{1}{2} ab \sin. C$. Substituting this in the formula for the spherical excess, we obtain in seconds, $E = \frac{ab \sin. C \times 648000}{2r^2 x}$: this formula is deduced on the hypothesis that the surface of the triangle is spherical; but it equally applies to triangles on the surface of a spheroid; for the spherical excess is the same for triangles on a spheroid and sphere, when the latitude of the stations and their differences of longitude are the same. To compute the spherical excess of any triangle, the value of r, the radius, should be ascertained; the curvature of the arc joining any two points or stations on a spheroid varies with the latitude, and also with the direction of the arc in respect of the meridian: the value of r may then be considered sufficiently near the truth, by assuming its value that which corresponds to the curvature of the meridian at the mean latitude of the stations, and even to suppose it constant for all the triangles within similar parallels of latitudes. To calculate the two remaining sides of the triangles after the three spherical angles have been determined, one side being always known either by measurement or computation, three different methods have been adopted: the first is to transform the side whose length is already known in feet into an arc of a circle, which is done by comparing it with the radius of the earth, and solving the triangle by spherical trigonometry. But this process is not generally adopted; that which was followed in calculating the triangles of the Ordnance survey was to consider, as the distance of any two stations mutually visible from each other is very small in comparison of the whole circumference of the earth, the chord of the intercepted arc will differ from the arc itself, by a quantity which may be computed from the known ratio of the chord to the radius of the earth, but which in general is so small as to be insensible. If, therefore, from the observed spherical angles we deduce in each case the corresponding angles formed by the chords, and with these compute the sides by plane trigonometry, we shall obtain the chords of the arcs intercepted between the stations, and thence the arcs themselves. The third method was after the demonstration, that a triangle on a sphere or spheroid, which is small in comparison with the whole spherical surface, differs insensibly from a plane triangle, of which the sides are respectively equal in length to the sides of the triangle on the sphere, and whose angles are respectively equal to those of the spherical triangle, each diminished by one third of the spherical excess.

Tables for the reduction of spherical angles to the plane of the chords, and likewise for the computation of the spherical excess, are given by Delambre in his *Base Metrique*.

To determine the Meridian Line the theodolite is fixed at one of the stations; and some hours before mid-day the telescope is directed, in such a manner that the cross-wires shall touch the upper or lower limb of the sun in the east; and then the horizontal and vertical readings of the arc are to be set down; this operation is to be repeated several times: in the afternoon, the vertical arc being clamped to the last reading off, the horizontal angle at the time of the sun's limb touching the intersection of the cross-wires is to be noted; the vertical arc being clamped in succession in the descending series of the vertical angles, all the horizontal readings at the time of each successive intersection are entered: the

point on the horizontal limb half-way between all the readings will give the angle to which the vernier is to be placed, in order that the telescope may point to the position occupied by the sun at noon.

On the Mensuration of Distances, Heights, &c., by the calculation of Sines, Tangents, and Secants. — By the terms sines, tangents, and secants, is understood the knowledge of the sides and angles of triangles, by means of which, and the assistance of tables calculated for the purpose, we can obtain the length of the unknown sides and angles.

A Sine is the side of a right-angled triangle, the hypotenuse of which has served as a radius to describe a circle comprising the right-angled triangle, as A B C, the hypotenuse of which, A B, is the radius of the circle D B E F G, which encloses the triangle A B C, the side of which, B C, is the sine of the angle C A B; for the same reason the side A C is the sine of the angle A B C, and the hypotenuse A B that of the angle A B C. Every angle of a triangle is the sine of its opposite side, as in that of A B C: the angle C A B is the sine of the side B C, which is opposite to it; and the angle A B C is the sine of the side A C; and the angle B C A is the sine of the hypotenuse A B.

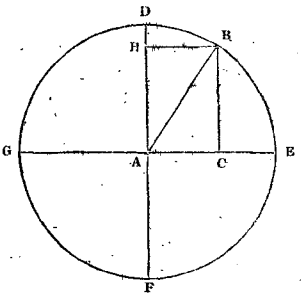


Fig. 1077.

Total sine, radius, sine of 90°, or entire sine, is the hypotenuse of a right-angled triangle, which serves as a radius to describe a circle enclosing a right-angled triangle. In the triangle A B C, the hypotenuse A B is a total sine, and the two other sides A C and B C are only sines; so that the total sine A B, being commonly divided into 100,000 parts which are equal, the two other sides or sines being each smaller, must have less than that number.

Right Sine of an Angle is a line which falls perpendicular from the point where the hypotenuse cuts the circle, on to the extremity of another line, which forms an angle with the hypotenuse, as the line B C is the right sine of the angle C A B.

Sine of an Arc is the right line drawn from one extremity of the arc perpendicularly to the radius which answers to the other extremity, as the right line B C is the sine of the arc B E.

Versed Sine is the remaining portion of the radius which is comprised between the line of the right sine of an angle and one of the same sine, as the line C E is a versed sine.

Sine of the Complement of an Arc is a right line drawn from the extremity of an arc, perpendicular to the radius, which does not touch the arc, but which together with the arc terminate a quarter circle: the line B H is the sine of the complement of the arc B E; because the right line B H is drawn from the extremity B of the arc B E, perpendicular to the radius A D, which does not touch the arc D B, which bounds it.

The reason why each side of a right-angled triangle inclosed within a circle is called a sine is said to be from the word *sinus*, signifying the heart, the most inward part of man; thus, sines, which are likewise enclosed or rather found inscribed in a circle, are called so; and as the heart is the most important part of man, so are sines in a circle those which produce the most useful acquirements in mathematics.

Tangents and Secants. — A tangent is a line which touches the circumference of a circle, but does not cut it if prolonged, as B C: tangent of an angle is a line perpendicular to the extremity of a radius at the point on which it touches the circle, and this perpendicular terminates at the other line, which forms the angle of the tangent with the radius; the right line B C is the tangent of the angle B A C, because it is perpendicular to the extremity of the radius A C, at the point C, where it touches the circle D C E F; and the perpendicular B C terminates at the line A B, which together with the radius A C forms the angle B A C of the tangent B C.

A Secant is a line which is drawn from the centre into the circumference of a circle, as the line A B is a secant; for being drawn from the centre A, it cuts the circumference of the circle D C E F in the point G.

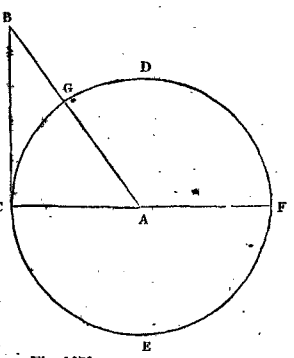


Fig. 1078.

Secant of an Angle is a line drawn from the centre of a circle, which cutting the circumference extends to the tangent; as the right line A B is the secant of the angle C A B, because it is a line drawn from the centre of a circle into its circumference D C E F, in the point G, and extends beyond the circle to the tangent B C.

OF TABLES OF SINES, TANGENTS AND SECANTS, AND OF LOGARITHMS.—In practical geometry the instruments mostly used have their degrees usually divided into six equal parts, and consequently the tables are calculated to answer them by having their degrees divided into six equal parts of 10 minutes each.

The sines, tangents, &c., are comprised in two sets of tables; the first contains the sums of progression of common sines and tangents for the 90 degrees of the quadrant, for the 100,000 parts into which its radius or entire sine is supposed to be divided. The second table contains the logarithms from 1 to 10,000: in the first table the *first* column contains the minutes of degrees, the *second* the sines answering in order to the minutes, the *third* and *fourth* the tangents and secants, the *fifth* the degrees, the *sixth* and *seventh* the logarithmic sines and tangents. The first column of minutes contains six divisions; the first is the minute, and then follows 10, 20, 30, 40, 50, 60, which answer to the five columns against them. The second column contains the sums of sines according to the progression of degrees and minutes of the radius or total sine, and the other columns contain tangents, secants, sines, logarithmic sines, and tangents; whilst the fifth serves to mark the degrees from top to bottom to 45 degrees for the left-hand columns, and from bottom to top from 45 to 90 degrees for those on the right-hand.

To find the Sine of an Arc, or the degrees of a given angle and its complement.—Every arc in a given angle may have less or more than 90°, and its degrees may have minutes or not. Required the sine of an arc of 24°, or simply the sine of 24°, look in the table under the head of degrees for this number, and against it is found 40673 for its sine; but if it is required to find the sine of 24° 10′, we must further seek for 10′ under the head of minutes, where, opposite to 24°, also in the column of sines, is 40939, which will be sine of 24° 10′. If it is required to seek the sine of 60° in the table which goes from 45 to 90; when the sine is 140°, or exceeds a quadrant, or 90°, we must take the complement by subtracting 140° from 180°, the value of a demicircle, and the remainder 40° must be sought in the column of sines, which will give 64278.

To find the Degrees and Minutes of a given Sine, as that of the sine 40673.—Seek the sine in the column of sines, and the figure opposite in the column of degrees will give 24°, and opposite this sine 40673 in the column of minutes is an 0, which signifies that the sine has no minutes; if the given sine had been 40939, seek it in the column of sines, and having found it in the left-hand columns, observe what degrees and minutes correspond with it, and having remarked it to be 24° 10′, set it down as the sine required. The rules above given for finding sines apply also to tangents and secants, both simple and logarithmic: when the distances measured are in feet or inches, it is necessary to reduce these dimensions into seconds, because these small fractions become less considerable, as fractions of lines in great distances are of little importance in a practical point of view.

To distinguish when observing objects, if the Sides of the Triangles formed are either Sines, Tangents, or Secants.—In a right-angled triangle, when we know the hypotenuse, or the side opposite the right angle, the sides of this triangle are considered the sines, because, if from one extremity of the hypotenuse, with its length as a radius, we describe a circle, it will inclose the whole triangle, and there will be neither tangent nor secant; supposing it required to find the distance from A to C, by employing a right-angled triangle A C B, of which the two angles B A C and A B C are known with the hypotenuse B C; it is evident that if from the point B, the extremity of the hypotenuse B C, and with the radius or length B C, we describe a circle, as D C E F, it will enclose the triangle A C B, and its sides A C and A B will be sines, because they are enclosed in the circle D C E F. Observe also, that in the same right-angled triangle A C B, that it is a general rule when one of the two sides are known which form a right angle, as for example B A, we can use it as a radius or total sine, to describe a circle, as A G H I; that the other side A C of the right angle B A C is a tangent, because it falls perpendicularly on the extremity of the radius B A at the point A, where it touches the circle; and that the side B C, which is opposite to the right angle B A C, is a secant, because it cuts the circle A G H I in K.

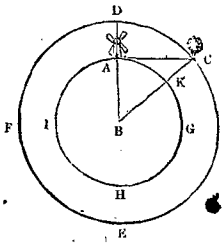


Fig. 1079.

In trigonometry, all the sides of acute and obtuse-angled triangles are called sines, because these triangles, having no right angle, can have neither tangent nor secant of angles: if it be required to find the distance L M by the obtuse-angled triangle L M N, it is clear that having no right angle, it can be neither the tangent nor secant of an angle.

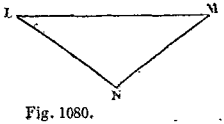


Fig. 1080.

To measure lengths by the calculations of Sines, forming a right-angled triangle, of which the hypotenuse and two angles are known, viz. right and acute.—To find the unknown angle, subtract the acute angle from

90°, the remainder will be the unknown angle; to find the two other unknown sides, proceed by the rule of three, placing in the first term 10,000, in the second the value of the known hypotenuse, and in the third the sine of the angle opposite to the side required: the quotient will give the unknown side. As to find the length A B by forming a triangle A B C, of which the hypotenuse C B is 108 feet, the acute angle A C B 50°, and the right angle C A B 90°. To find the unknown angle C B A, subtract the acute angle A C B, 50°, from 90°, the remainder, 40°, will be the angle C B A; then place for the first term 10,000, in the second the length of the hypotenuse reduced to seconds, as 15552, and the third term the sine of the angle A C B 50°, which sought for in the tables is found to be 76604; the quotient will give 11913 seconds, and the remainder 45408 is about one half second more, consequently the length of A B is 82 feet, 4 inches, 8 seconds, 9½ thirds. To obtain the side A C, you must adopt the same method.

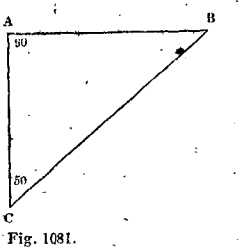


Fig. 1081.

Another example may be given: where the length of the hypotenuse is not known.— From 90° subtract the known acute angle, the remainder will be the unknown angle; to find the length of the unknown side which forms the right angle and is a tangent, place in the first term, as before, 10000, in the second the known side, in the third the tangent of the angle opposite to the required angle: the quotient will be the length. The height A C of the triangle A B C, of which the side A B is 11913·5 seconds, the angle C B A 40°, and C A B 90°, it is required to find the height A C; subtract from 90° the acute angle 40°, and the remainder 50° will be the acute angle A C B. Then place in the first term 10,000, in the second 11913·5, and in the third the tangent of the angle, 40°, which will be 83909, according to the tables; the quotient gives 9996 seconds for the height A C, which reduced to feet is 75 feet 5 inches. If the length of the hypotenuse is required, place in the first term 10000, in the second the length of the side A B, 11913·5, and in the third place the secant of the angle, 40°, which is 130540 in the table, and the quotient gives 15551, with a remainder of 88290, or nearly one-third of a second, consequently the hypotenuse is in length 15551⅓ seconds, or 108 feet nearly.

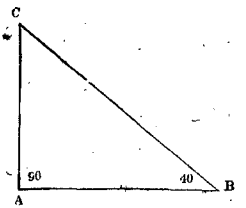


Fig. 1082.

Required the length A B of the third triangle, having formed the right-angled triangle A B C, of which the hypotenuse C B is 108 feet, 15551⅓ seconds, and the side C A is 69 feet 5 inches. First find the acute angle A C B opposite the required side A B by the unknown angle C B A, which you can obtain by the simple rule of three, placing in the first term the value of the hypotenuse C B, in the second term 10000, and in the third term the length of the side A C; the quotient will give 64277 for the sine, which being sought in the table and not found, seek the nearest number to it, 64278, which will give 40° for the angle C B A; subtract from 90°, the angle C B A, 40°, and the remainder, 50°, will be the angle A C B. To find the side A B, adopt the rule given for the first triangle, that is to say, by the rule of three, placing in the first term 10000, in the second the length of the hypotenuse, and in the third the sine of the angle A C B 50, opposite the required side A B, which sought in the tables will be 76604; the quotient of the sum will give 11913 seconds; there will remain 45408, which is half a second, and which reduced into feet gives 82 feet, 4 inches, and 9½ seconds.

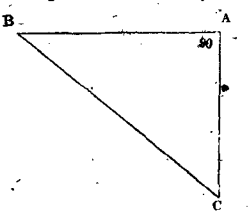


Fig. 1083.

Required the distance from B to C, having formed the right-angled triangle A B C, of which the side A B is 82 feet, 8 inches, 9½ seconds, or 11913½ seconds; and the side A C is 69 feet, 5 inches, and half a second, and the angle B A C a right angle of 90°. It will be seen that since we do not know the hypotenuse, B C, we must work by tangents and secants. To find the required side B C, we must know one of the two acute angles, as C B A, opposite to the short side A C, 9996½ seconds. To find this by proportion, place in the first term the length of the side A B, 11913½ seconds; in the second term 10000, and in the third term the side A C, 9996½ seconds; the quotient will give 83912, which, being a tangent, seek the nearest number to it, 83909, in the table, it will give 40 degrees for the angle C B A.

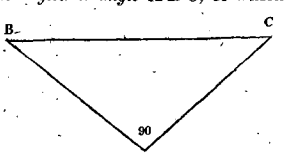


Fig. 1084.

If you desire to measure the acute angle A C B, it will only be necessary to subtract 40° from 90°, the remainder, 50°, is the angle. To have the length of the hypotenuse, or side B C, follow the rule given for the second triangle by proportion, placing in the first term 10000, in the second the value of the side A B, 11913½ seconds, and in the third the secant of the angle C B A, 40°, which is 130540: the quotient will give 15552 lines for the distance B C, which, reduced into feet, will give 108 feet.

It is required to find the distance A B, having formed an acute-angled triangle, A B C, the angle A C B is supposed to be 79°, the angle C B A, 37°, and the length of the side C B, 58 feet. To find the angle C A B, add together the two known angles, 79° and 37°, and subtract their sum, 116°, from 180°, the remainder, 64°, will be the value of the angle C A B. To obtain the length of the side A B by proportion, place in the first term the sine of the angle C A B, 64°, opposite the known side, A B, 58 feet; the sine will be 89879; in the second term the length of the side C B 58 feet; in the third term the sine of the angle A C B, 79°, opposite the required side; this sine will be 98162; the quotient will give 63 feet for the side A B, and since there remains 31019, reduce them into inches and seconds. If the side A C is required, place for the first term the sine of the angle C A B, 64°, viz. 89879, for the second term the value of the side C B, 58, and in the third term the sine of the angle C B A, 37°, which is 60181; the quotient will give 38 feet for the length of the side A C: what remains must be reduced into inches and seconds.

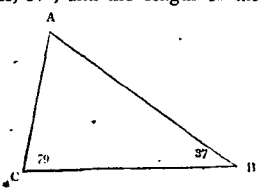


Fig. 1085.

Required the distance from A to B, the side A C having 46, C B 66, and the angle C A B, 81°. First find the angle C B A, opposite the known side A C, by proportion: place in the first term the length of the other side, C B, 66, opposite the known angle, C A B, 81°. In the second term the sine of the angle, C A B, 81°, which is 98768, and in the third term the length of the known side, A C, 46, opposite the angle sought, C B A; the quotient, 68838, will be the sine: seek the nearest number in the table, 68835, which will give 43° 30′ for the angle C B A. Add the sums of the two triangles C A B, 81°, and C B A, 43° 30′, their sum, 124° 30′, subtracted from 180°, leaves 55° 30′ for the angle A C B. Then find the length of the side A B, by the rule before given. Place in the first term the sine, 98768, of the angle C A B, 81°, opposite the side C B, 66; in the second term, the value of the known side, C B, 66, and in the third term, the sine, 82412, of the angle A C B, 55° 30′, opposite the required side, A B; the quotient will give 55 for the length of A B, with a remainder.

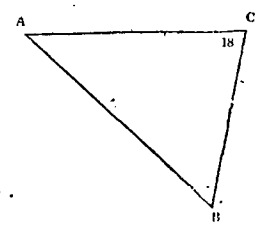


Fig. 1086.

Measuring Lengths by the calculation of Sines, forming an acute-angled triangle, of which two sides and the comprised angle are known. Required the distance from A to B, by forming an acute-angled triangle A B C, the side of which A C is 60 chains, B C 30 chains, and the angle A C B comprised by these two sides 69°. To find the two angles C A B and C B A, add together the two sides, A C 60 chains, and B C 30 chains; their sum will be 90°; subtract the short side, B C, 30, from the long side, A C, 60; there remains 30: subtract from 180° the known angle A C B 69°; the remainder, 111°, will be the value of the two unknown angles, C A B and C B A, of which take the half, 55° 30′. Place in the first term the sum of the two sides, A C 60 and B C 30 = 90; in the second, the difference of the two sides 30, and in the third term the tangent of half the two unknown angles 55° 30′, which is 145500; the quotient will give another tangent, 48500, the nearest number to which in the tables, 48413, will give 25° 50′, to which add half the value of the unknown angle 55° 30′, and it will give 81° 20′ for the greatest angle of the two, viz. C B A, but if you subtract the 25° 50′ from 55° 30′, it will give 29° 40′ for the angle C A B. To find the side A B by proportion, place in the first term the sine of the angle C A B 29° 40′ opposite the side B C, 30 chains; this sine will be 49495; in the second term the side B C 30 chains, and in the third term the sum of the angle A C B 69° opposite the side required; this sine will be 93358; the quotient will give 56 chains for A B. If you would reduce the remainder 29020 chains into feet, you will have 14 feet more, which gives 54 chains 14 feet for the distance from A to B.

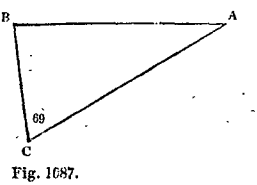


Fig. 1087.

Measuring Lengths by forming an Obtuse-Angled Triangle, of which two angles and the

adjacent side are known. This method is almost the same as that for the fifth triangle, only instead of taking the sine of the obtuse angle, we take the sine of its complement, as will be seen in the following example. - Required the distance from A to B, having formed the obtuse-angled triangle A B C, of which the angle C A B 33°, A C B 109°, and the adjacent side A C 52 feet. To find the unknown angle C B A, add together the value of the two known angles C A B 33°, and A C B 109°, and subtract their sum, 142°, from 180°; the remainder, 38°, will be the value of the unknown angle C B A. To find the length of the unknown side A B by the rule of three, place in the first term the sine of the angle C B, 38°, opposite the known sine A C; this sine will be 61566; in the second term the value of the known side A C 52, and in the third term the sine of the angle A C B 109, opposite the side required. But since this angle A C B is 109° and we have no sine above 90° we must take the sine of the complement of 109°; that is to say, we must subtract the obtuse angle A C B 109° from 180°; the remainder will be 71°, and the sine of 71° will be 94551, which must be put in the third term; the quotient will give 79 with a remainder for the length A B.

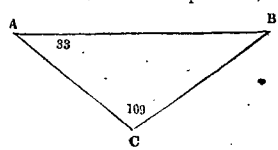


Fig. 1088.

It will be seen that all the other difficulties which might attend the obtuse-angled triangle are reduced to the rules for the acute-angled triangle, provided it is remembered that to have the sines of obtuse-angled triangles the complement of 180° must be taken.

To find the three Angles of a Triangle, when the three sides are known, by the calculation of sines.—Since this difficulty may occur in the three kinds of triangles, right, acute, and obtuse-angled we will commence with the first, viz. the right-angled. In the triangle A B C, the three angles of which we wish to ascertain, let it be supposed that the side A B is 11913 seconds, A C 9996, and C B 15552; to find the three angles, let fall a perpendicular A D from the angle C A B to the side C B; add together the two sides A B 11913 and A C 9996; their sum will be 21909; subtract the shorter side A C from the mean A B, to have their difference 1917: then by proportion, placing in the first term the greatest side C B, 15552, in the second the sum of the two sides A B and A C, 21909, and in the third term the difference 1917; the quotient will give 2700, with a remainder of 9153, which is nearly two-thirds of the difference between the two segments C D and D B, and this difference being subtracted from the half length C B leaves 12851⅔, of which take half for the small segments C D, and if to this half, 6425$\frac{11}{12}$, you add the difference, 2700⅓, between the two segments, you will have for the other segment, D B, 9125⅓. Before proceeding further, value the small portions of the two segments C D and D B, and it will give 6425⅔ for C D, and 9126⅓ for D B. To find the angles of the two right-angled triangles, A D C and A B D, of which we know the hypotenuse and one side, follow the rule of the third triangle. To find the two acute angles D A C and D C A of the right-angled triangle A D C: by proportion, place in the first term the hypotenuse A C, 9996, in the second 100000, and in the third the side C D, 6425⅔; to have the opposite angle D A C, the quotient will give 64282, which will be a sine; seek the nearest number in the table, 64278, which will give 40° for the angle D A C, which subtracted from 90° leaves 50° for the other angle D C A: by the same rule it will be found that the angle D A B in the right-angled triangle A B D is 50° and D B A 40°: add these together; their sum will be 90° for the third angle C A B of the right-angled triangle.

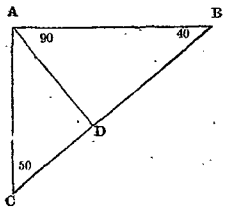


Fig. 1089.

Mensuration of Distances, Heights, &c. by Logarithms, which facilitates the calculations of sines, and avoids the necessity of calling in the aid of proportion, addition, and subtraction with them, hold the place of multiplication and division, as has been seen in preceding examples; here we shall repeat them, to show the convenience of logarithms in calculating sines, tangents, and secants. We have already mentioned that sines give halves, thirds, quarters, &c., by reason of their remainder, after their division; logarithms only give integers, which obliges us to reduce the value of the known sides into small measures, as far as 4000 (the number given in the ordinary tables), which is a sufficient quantity to be appreciated in mensuration.

Measuring Lengths, by forming a right-angled triangle, of which the hypotenuse, with the right and acute angles are known. To find the third angle, subtract from 90° the value of the known acute angle; the remainder is the third unknown angle: then to find the side opposite to the acute angle just ascertained, seek in the logarithms, in the column of numbers, the number of the length of the hypotenuse figured apart. Then seek in the table of sines, in the column of logarithmic sines, the logarithmic sine of the acute

angle opposite to the side to be known, to add to the logarithm already figured a part, and subtract their sum from the logarithm of the sine 100000000, which is the end of the column of logarithmic sines, where the 89° 60′ of the tables of sines end; the remainder of this subtraction will be a logarithm, which sought in the table of logarithms will give the value of the required side.

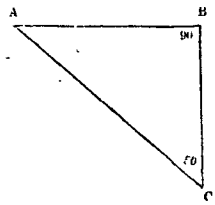


Fig. 1090.

Let it be required to find the distance A B: having formed the right-angled triangle A B C, of which the hypotenuse C B is known to be 1296 inches, and the acute angle A C B 50°, with the right angle C A B 90°. To find the third angle C B A, subtract the acute angle A C B 50° from 90°; the remainder, 40°, will be the acute angle C B A. To find the inaccessible side A B, seek in the column of numbers the sum of the hypotenuse B C, 1296, which will give the logarithm 31126050. Then seek in the column of sines of logarithms the logarithmic sine of the angle A C B, 50°, opposite the side required, A B; the logarithmic sine will be 98842540, which add to the logarithm figured aside, and from their sum, 129968590, subtract the total logarithmic sine 100000000; the remainder, 29968590, will be a logarithm, which being sought, or its nearest number, 29969492, will give opposite in the column of numbers 993 for the length of the side A B in inches: according to the same rule it will be found that the side A C is 833 inches long.

Measuring Lengths, by forming a right-angled triangle, of which one of the sides which form the right angle is known, with the adjacent right and acute angles. To have the third unknown angle subtract the known acute angle from 90°; to have the other side, forming the right angle, which is a tangent, seek in the column of numbers the length of the known side, and write down the logarithm opposite it. Then seek in the table of sines the tangential logarithm of the angle opposite the side to be found, which add to the logarithm written down, and from their sum subtract the total logarithmic sine 100000000; the remainder will be a logarithm, which being sought in the column of logarithms, will give in the opposite column of numbers the side required.

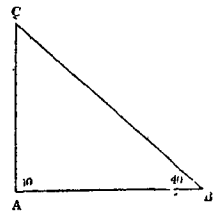


Fig. 1091.

Required the height A C of the right-angled triangle A B C, where the side A B is 993 inches, the right angle C A B 90°, and the acute angle C B A 40°. We know that by subtracting the acute angle C B A, 40°, from 90°, the remainder 50° will be the unknown angle A C B. To have the height A C, which is a tangent, seek in the column of numbers the side A B, 993 inches, to take its logarithm 29969492: seek in the table of sines the tangential logarithm of the angle C B A 40°, opposite the side required; the tangential logarithm will be 99228135, which add to the logarithm before found; their sum will be 129207627; subtract the total logarithmic sine 100000000 from it; the remainder, 2920762, will be the logarithm, which sought in the table of sines will give 833 inches, opposite its nearest number, 29205430, for the height required of A C. To have also the hypotenuse C B, add the total logarithmic sine, 100000000, to the logarithm 29206450, and from their sum, 12906450, subtract the logarithmic sine 98080675, of the angle C B A 40°; the remainder, 31125775, is a logarithm, which sought in its nearest number, 31126050, in the table, will give 1296 for the hypotenuse C B.

Of measuring Lengths by forming a right-angled Triangle, of which the hypotenuse and one of the sides which form the right angle and this angle are known. To find the third unknown side, add to the length of the hypotenuse that of the known side; seek their sum in the column of numbers and figure the logarithm, which is opposite, by itself; then subtract the known side from the value of the hypotenuse; seek the remainder in the column of numbers, take the logarithm opposite, to figure it above or below the last logarithm; add the two together, and take half their sum, which being a logarithm, seek it or the nearest number to it in the table, the number opposite marks the length of the unknown side.

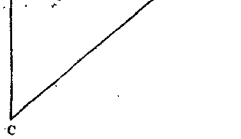


Fig. 1092.

Required the distance from A to B having formed a right-angled triangle A B C, of which the hypotenuse C B is 1296 inches, and the side A C 833 inches, with the right angle C A B, 90°.

To find the side A B, add the hypotenuse 1296 to the side A C 833; seek their sum in the column of numbers, which will give the logarithm 33281757. Then subtract the side

A C, 833, from the hypotenuse C B, 1296; their remainder, 463, seek in the column of numbers; write the logarithm, 26655810, which is opposite, below the first logarithm; add these two together, their sum will be 59937567, and its half 29968783½ will be a logarithm; seek this or its nearest number 29969492 in the column of logarithms, which will give in the column of numbers 993 for the number of inches from A to B.

Of measuring Lengths by forming a right-angled Triangle of which the two sides forming the right angle and the latter are known. — Required the distance B C, having formed a right-angled triangle A B C, of which the side A B is 82 feet, 8 inches, 9½ seconds, or rather more than 993 inches, the side A C 833 inches; and the angle B A C 90. One of the two acute angles must be found, say C B A, opposite to the shortest known side A C, 833 inches. Write down the total logarithmic sine 100000000. Then seek in the column of numbers the figure 833, the value of the side A C, which is that opposite the angle required, C B A; and take the logarithmic sine, and add them together: their sum will be 129206450. Seek in the column of numbers, the figures of the other side A B, 993 inches, and having found them, take the opposite logarithm, 29969492, which write below the sum 129206450; subtract one from the other, the remainder, 99236958, will be a tangential logarithm, which, or the nearest number to it, 99238135, you must seek in the column of tangential logarithms; in the opposite column of degrees will be found 40° for the angle C B A: if you subtract this angle from 90° there will remain 50° for the other acute angle A C B. Lastly, to find the distance B C, which is a secant, add to the total logarithmic sine 100000000, the logarithm 29969492 of the side A B, 993 inches, and from their sum 129969492, subtract the logarithmic sine of the angle A C B, 50°, which is 98842540, the remainder 31126952 is a logarithm; which, or its nearest number 31126050, will give 1296 for the required distance B C, in inches.

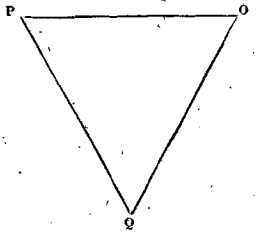


Fig. 1093.

Measuring Lengths by forming an acute-angled Triangle, of which two angles and the adjacent angle are known: to find the third angle, add together the value of the two known angles, and subtract their sum from 180°; the remainder will be the unknown angle. To find the two unknown sides, as that which is opposite to the least angle, seek the logarithmic sine of the angle, and write it down: then seek in the column of numbers the value of the known side, figure its logarithm below the logarithmic sine before found, add the two together, and from their sum subtract the logarithmic sine of the angle opposite the known side; the remainder will be a logarithm; which being sought in the column of logarithms will give in that of numbers the length of the unknown side.

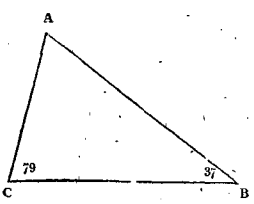


Fig. 1094.

Required, in the acute-angled triangle A B C, the distance from A to B; the angle A C B, being 79°, C B A, 70°, and the adjacent side C D, 3480 inches. To find the angle C A B, add together the two angles A C B 79° and C B A 37°: subtract their sum 116° from 180°, the remainder 64° will be the unknown angle C B A. To have the length of the side A B, seek in the table the logarithmic sine of the angle A C B, 79°, opposite the side A B required to be found; this logarithmic sine will be 99919466: then seek in the column of numbers the length of the known side C B, 3480 inches, which will give opposite the logarithm 35415792, which write below the logarithmic sine 99919466; add them together, their sum will be 135335258. Lastly, seek in the table the logarithm of the angle C A B 64°, and it will be 99536602, which subtract from the sum 135335258, the remainder, 35798656, will be a logarithm, the nearest number to which, 35797836, will give 380 for the distance in inches from A to B.

Of measuring Lengths, by forming an acute-angled triangle, of which two sides and the comprised angle are known. Required the distance from A to B of the acute-angled triangle A B C, of which the side A C is 1440 feet, C B 720, and the angle A B C 69°. To find one of the two unknown angles, subtract the short side B C, 720, from the long one A C, 1440, their difference, 720, will give the logarithm, 28573325. Subtract the known angle A C B 69° from 180°, the remainder 111° is the value of the two unknown angles, of which take the half, 55° 30′, their tangential logarithm in the table of sines will be 101628657, which add to the logarithm 28573325; their sum will be 130201982. Then add together the sides A C 1440, and B C 720; their sum, 2160, will give the logarithm 33344537, which must

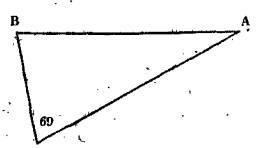


Fig. 1095.

be written below the sum total 130201982, and subtracted from it; the remainder, 96857445, will be a tangential logarithm, the nearest number to which, 96849681, will give 25° 50′, which being added to the 55° 30′, the approximating value of the two angles, will give 81° 20′ for the greater angle C B A, and 25° 50′, being subtracted from 55° 30′ there will remain 29° 40′ for the angle C A B. To find the third side A B take the logarithmic sine of the angle A C B, 69°, opposite the side A B; this sine will be 99701517. Then seek in the column of numbers the logarithm of the side B C, 720, which will be 28573325; figure it below the logarithmic sine 99701517, and add them together; the sum will be 128274842. Seek the logarithmic sine of the angle C A B, 29° 40′, opposite the known side B C; it will be 96945642, which subtract from the sum 128274842, the remainder, 31329200, will be a logarithm, the nearest number to which in the table will give 1358 for the distance in feet from A to B.

Measuring Lengths by forming an obtuse-angled Triangle, of which two angles and the adjacent side are known: the rules for the first acute-angled triangle must be applied here; nevertheless, since in the table of sines there are no logarithmic sines for obtuse angles, we must subtract the obtuse angle from 180°, and take the logarithmic sine for the remainder or complement. Required the distance A B, having formed the obtuse-angled triangle, A B C, of which the angle C A B is 33°, the angle A C B 109°, and the adjacent side A C 312 feet. To find the third angle C B A, add the two angles C A B, 33°, and A C B, 109°, together, and subtract their sum 142° from 180°, the remainder 38° will be the required angle C B A. To have the length of the required side A B, seek the logarithmic sine of the angle A C B, 109°, opposite the required side A B; but since the angle A C B 109° is obtuse, subtract 109° from 180°, the remainder 71° is its complement; the logarithmic sine of which is 99756701. Then seek in the column of numbers the side A C 312; write down the logarithm which is opposite 24941546, below the logarithmic sine 99756701, and add them together; their sum will be 124698247. Seek the logarithmic sine of the angle C B A 38° opposite the side A C, it will be 97893420, which subtract from the sum 124698247, the remainder 26804827 will be a logarithm, the nearest number to which in the table, 26803355, will give 479 for the distance A B in feet.

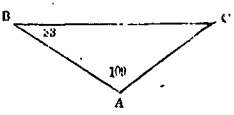


Fig. 1096.

By the same rule it will be found, that the side C B is 276 feet, remarking that there is no sine of the complement to be taken for the angle C A B because it does not exceed 90°.

As for the other obtuse triangles, they are solved like acute-angled, only taking the complements of the obtuse angles.

MENSURATION OF SUPERFICIES AND SURVEYING. — *Of Bevels and Recipiangles.* — A bevel may be compared to a pair of large compasses, and is usually made of iron or wood: the iron bevel A, used by stone masons, has each of its branches about 2 feet long, smooth and pointed, and its head, which is round, will open to any angle required.

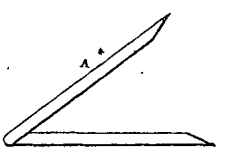


Fig. 1097.

The carpenter's bevel, B, made of wood, is commonly shorter than the stone-mason's; the extremity which forms its head is cut at right angles, so that opening them to the square mark they may serve more easily to express a right angle.

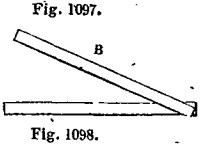


Fig. 1098.

The Recipiangle C consists of two long rules of wood, which have their branches parallel at their edges, and are attached together at the middle of their ends by a double-headed screw, which forms the head of the instrument. When used for taking salient and re-entering angles, the centre of a protractor of wood or horn, 6 or 8 inches in diameter, is applied at D to the point at which the branches cross, to observe how much the branches are opened, and which give the required angle; in default of this instrument we use a bevel.

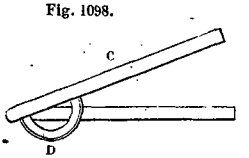


Fig. 1099.

The recipiangle E, made of wood, copper, &c., is composed of two plates, each about a line in thickness, 12 inches long, and 3 inches wide: sometimes its length is increased by adding slips of wood or flat rulers. At the extremity of one of the two plates is described a demi-circle, equal to its breadth, divided into 180°; and at the extremity of the second blade, towards its centre, is a small tongue or round head, which is attached to the centre of its semicircle on the other limb by a double-headed screw.

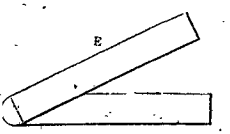


Fig. 1100.

The instruments described are extremely simple and have this fault, that it is difficult to apply the centre of a protractor

precisely to the point where their limbs cross; and that marked E can only carry a small protractor, on account of the size of the circle on which it is mounted; wherefore the demicircle, having its sines very small, cannot give the just value of an angle, and we cannot observe halves and quarters of degrees, which are necessary to set out the angles precisely.

Of the Parallelogrammic Recipiangle. — The two limbs A B and A C, of any length and breadth, are joined together at the point A by a double-headed screw; they are pierced in the centre of their breadth at the points D and E, equidistant from the centre A; and to these holes are attached two small rules, D F and E F, joined at the centre F, in such a manner that the four rules A D, D F, F E, and E A, when the four centres of motion are of an equal length, form a perfect square. On the rule E F G, which is longer than D F, is attached a protractor with two hinges G and H. The centre of the protractor should be above the centre of the screw F, and the line of its diameter, if prolonged, should pass through the centre of the screw E: its radius should be rather less than the side F D, to allow a small line to be seen on the piece attached to the screw D, which serves to indicate the angle on the margin of the protractor. The recipiangle is used for taking re-entering angles, but when salient angles are required, it is only necessary to open the long rules A B and A C in a right line, and then the centre F will coincide with the centre A, so that the same sides of the long rules which have served to take the re-entering angles will also serve to take the salient. When taking small re-entering angles and salient angles, the protractor must be elevated perpendicularly off its rules by means of two hinges, and then laid down to measure the angle.

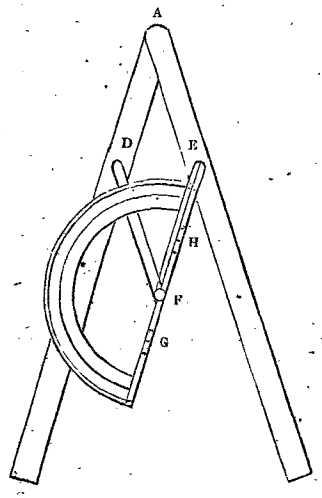


Fig. 1101.

To draw the Outline of any Place or to take its Plan. — As we can only take the plan of a place by the knowledge of the length of its sides and the measurement of its angles, the first thing to be done is to pass round it, and observe whether it is closed or not; if it is accessible and open, as most hamlets and villages are, an artificial outline must be made by planting piquets near the places to be taken, and on the most elevated ground. It must also be observed that in placing these piquets it is not necessary to plant them at equal distances, or that the outline should be formed with regular sides; all that the plan is to comprise should be so set out that its angles may be taken. If the place is only partly open, or if several trees or houses interfere, their position and measurement must be taken in the manner described hereafter. The outline of the plan being roughly sketched out on paper, when the measurements are taken, the sides and angles may be correctly set down in their true and relative positions.

When the plans of a large extent of country containing several towns and villages have been taken, the measurements of which differ, they must be reduced to one uniform scale; and if any marsh or water intervenes, which cannot actually be measured, recourse must be had to the trigonometric method.

To take the plan of any rectilineal Figure with the Recipiangle. — Required the plan of the ground A, of which the figure B C D E F G H has been drawn, and the length of the sides written along them, as B C 150, C D 81, &c. First take the angles of the ground, as B H G, with a recipiangle; then, having measured it from the angle, retain its opening, and apply the centre of a protractor to the point where the two branches cross, and the diameter of the protractor along one limb, and remark how many degrees are comprised between the limbs, as 93°, which write down on its corresponding angle: then, to obtain the re-entering angle, as G F E, place the head of the recipiangle in the angle required,

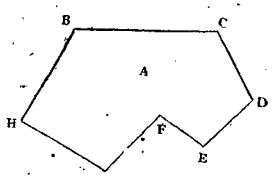


Fig. 1102.

and make the two branches of the instrument touch the two sides of the angle; then remove it, keeping it open, and place a protractor on the point where the two limbs cross, with its diameter along one of the limbs: the degree intercepted between the two limbs will be the required angle, G F E, 110°, which write down in the corresponding angle of the drawing:

if the salient angle B H G is required, take it between the limbs of the instrument, and observe on the demi-circle which is at the head, how many degrees are covered, and the number, as 93°, will be the required angle. Sometimes cords are attached to the several piquets, that the recipient may be more accurately applied where the angles are to be taken.

To draw out the Plan after the Angles are taken, commence with the line A B, which serves as a scale, and draw it of any length convenient, divided into any number of parts, as 150°; then at the upper part of the paper draw the line C D, on which set off 150 parts from the scale, to answer to the 150 feet of the scale A B: at the point E draw an angle of 121° equal to BCD on the ground, by placing the centre of the protractor at the point E, and its radius turned towards the side to be drawn, on the plan, and its diameter along the side C D; count from this line 121°, as to F, and draw through it a line, FG, which will form with CE an angle CEG, equal to B C D on the ground. To determine the side E G, take 81 parts from the scale A B, answering to the 81 feet from C to D on the ground, and set them off on the line E G, from E to H. At the point H draw an angle of 113°, answering to the angle C D E on the ground, and set off on the line H I, 73 parts of the scale, from H to K, to correspond with the 73 feet from D to E on the ground; then, at the point K, draw an angle H K L, with the protractor of 89° equal to D E F, and set off 55 parts of the scale A B from K to M, answering to the 35 feet of E F: from the point M, draw a re-entering angle, K M N, 110°, equalling E F G, by placing the centre of the protractor at M, its radius towards the plan to be drawn, and its diameter along K M, to count 110° from this line on the protractor: continue these operations for the sides and angles already set down on the rough plan, and the work will be complete.

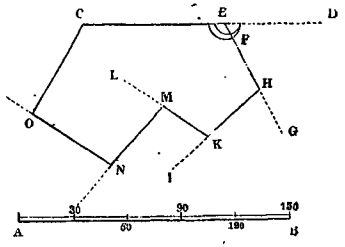


Fig. 1103.

To take the Plans of Streets and various other Places, &c.—To take the plan of a quay near the river side, draw a scale, as I K, and on a sheet of paper of any length, draw an oblique line, as at *a b*, to unite the quay, A L, which is skewed, the length of which is to be measured: set off the same quantity of feet taken from the scale, from *c* on the line *a b*; the line *a c* will represent the border of the quay, A L; after having measured on the ground how far the descent, R, is from the barrier, A, take a like distance from the scale, and set it off on *a b*, which will represent the descent of the point R: then remark that the border of the quay, A L, makes an angle with the other border, M N, which angle may be formed by stretching two cords, A L S and M N P, along the two borders, which will intersect at Q, and form the required angle, L Q N, which will serve as a fixed point: then measure the distance from the point Q, to the border of the quay, L, and from the point, Q, to the border, N, and measure the angle, L Q N: then take from the scale I K, the value of the distance L Q, and set it off on the line *a b* from *c* to *d*, and from this point, *d*, draw with a protractor *a d e*, equal to L Q N, and by means of the scale set off the distance G N on the line *d e*, from *d* to *f*: measure also the border of the quay, N M; take a like distance from the scale, set off on *f e*, from *f* to *g*, and do the same for the other parts of the quay. To have the breadth of the quay, place a square against the parapet, at the openings and descent, R L, M N, &c., opposite the streets which lead to the quay, with the other side of the square towards the houses, so that by stretching a cord, R S, along the square, the exact width of the quay may be obtained: then draw perpendicular lines on the paper representing the quay, and its descents, *h e f g n*; set off the distances on them of the different breadths of the quay, at the points *i, k, l, m, o*, through which draw the line to indicate the width of the street,

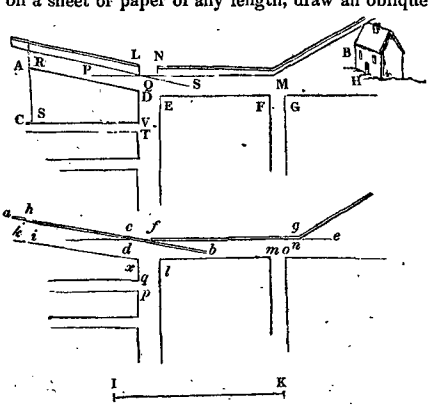


Fig. 1104.

extent of the houses, &c. Lastly, to have the angles of the streets, take them with a recipiangle, and their length and breadth by means of a cord and square; then draw with a protractor the various angles, as before described, and set off the breadths and lengths till the whole is completed. It must always be borne in mind that the three internal angles of every triangle are equal to two right angles, and make 180°. In the right-angled triangle, all its three angles taken together make 180°, as is seen by the space of a circle described from the point of each angle, comprised by the sides of the same angle. The same is the case with the obtuse-angled triangle and the acute. To have the angle of the centre of a regular figure, divide 360° by the number of sides of the figure, the quotient will give the angle.

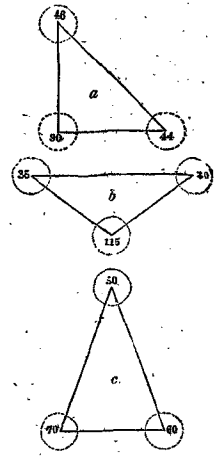


Fig. 1105.

In the regular hexagon *abcdef*, to have the central angle *aib*, divide 360° by 6, the number of sides of the hexagon, the quotient will give 60° for the angle, where it will be seen that whatever number of sides a regular or irregular figure may have, the central angles together equal 360°, because they occupy a circle described from the centre of the figure, and which is divided into that number of degrees.

To find the Polygonal Angles of a regular Figure, subtract from 180° one of the central angles, the remainder will be the polygonal angle.

In a regular hexagon subtract 60°, the central angle, from 180°, the remainder, 120°, will be the polygonal angle; multiply 120° by 6, the number of sides in a hexagon, and we have 720° for the six polygonal angles.

To have all the polygonal angles of an irregular figure, it is a rule for those of the same number of sides, both regular and irregular, that the sum total of the polygonal angles of the regular figures is equal to that of all the polygonal angles of the irregular figure.

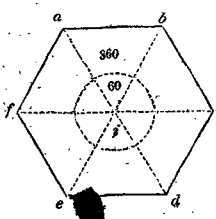


Fig. 1106.

If in a regular hexagon six lines are drawn from its centre to its six polygonal angles, the hexagon will be divided into six equal triangles; and as already stated, the three angles of a triangle are equal to 180°: we shall, therefore, have for the angles of the six triangles 1080°, and as the six central angles of the hexagon are equal to 360°; if from 1080° we subtract 360°, there remains 720° for the six polygonal angles of a regular hexagon. By the same rule it will be found that the six polygonal angles of an irregular hexagon are together equal to 720°, which is easily seen by drawing lines from its centre to its six polygonal angles, dividing the hexagon into six triangles, each of which is equal to 180°; we therefore have 1080° for the angles of the six triangles of the hexagon, and if we subtract 360° from 1080°, there remains 720° for the polygonal angles, which are equal to those of the regular hexagon.

To find in plans laid down, if the sum of the polygonal angles is correct, multiply 180° by the number of sides of the plan; from the product subtract 360°, the remainder will be the value of all the polygonal angles of the figure. In taking the polygonal angles of the irregular hexagon, the addition of the six polygonal angles gives 720, and if it is not known whether the sum is correct, to ascertain it, by the preceding rule multiply 180° by 6, the number of sides of the proposed hexagon; from the product 1080° subtract 360°, the value of all the central angles, the remainder, 720°, will be the number of degrees of the six angles of the irregular polygon; and since the sum of the angles of the polygon which have been taken agree exactly with this, it proves that they have been correctly taken.

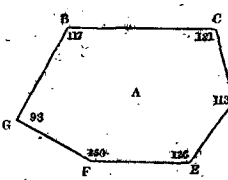


Fig. 1107.

To find whether the Polygonal Angles have each separately been correctly taken: by the second of the preceding rules it may be found if the polygon is regular; but if not, for example, in the angle D E F, take on the ground each angle of the complement, by means of a cord stretched in the line of the angle of the polygon required, and if, by adding together, the value of these two angles is equal to 180°, it may be concluded that the angle is

correctly taken; but if the sum of the addition is more or less than 180°, measure the angles again, to ascertain whence the error has occurred, and by successive operations correct it.

To find the salient and re-entering Angle of a Plan, if correctly taken, it is requisite to ascertain if the right angles of the irregular plan are equally so, viz. the salient angle, I B D, 76°, the re-entering angle B D C, 121°, the angle D C E, 103°, C E F, 113°, E F G, 89°, the re-entering angle F G H, 110°, G H I, 117°, and the salient angle H I B, 93°. Trace outside the two re-entering angles the lines B C and H F, which form an artificial boundary, B C E F H I; measure all the angles of this as if it were the true one, except the two C E F, 113°, and H I B, 103°, which are already known, and having found, by taking these angles, that I B C is 117°, B C E 121°, E F H 126°, and F H I 150°, which, together with the two angles C E F, 113°, and H I B, 93°, make 720°; then this shows that the angles are properly taken, because the polygonal angles of a hexagon, whether regular or irregular, together make 720°. But since the artificial boundary B C E F H I has the angle I B C, 117°, greater than I B D, 76°, B C E, 121°, greater than D C E, 103°, E F H, 126°, greater than E F G, 89°, and F H I, 150°, greater than G H I, 117°, therefore we must ascertain if the four angles I B D, 76°, D C E, 103°, E F G, 89°, and G H I, 117°, are correctly taken. For the first two angles I B D and D C E, measure in the artificial triangle B C D, the angles D B C, 41°, and D C B, 18°; then subtract D B C, 41°, from I B C, 117°; the remainder, 76°, being equal to the angle I B D, as measured, shows it has been accurately taken. If from the angle B C E, 121°, the angle D C B 18° is subtracted, there will remain 103° for the angle D C E. Pursue the same course for the angle E F G and G H I, and the first will be found 89°, and the second 117°.

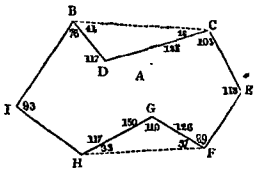


Fig. 1108.

To ascertain if the re-entering angles are properly taken, beginning with D B C, add to the artificial triangle B C D, the two angles D B C, 41°, and D C B, 18°, subtract their sum 59° from 180°, the remainder, 121°, will be the value of the re-entering angle B D C, which was before found the value of that angle: the same rule must be followed for the artificial triangle G F H, to ascertain if the re-entering angle F G H, 110°, has also been correctly taken. Lastly, to verify the two angles C E F and H I B, have recourse to the method before given, by using the complement of the angle

Taking the Plan of Places wholly or the part of a circular figure: such a plan must be enclosed within a cord, or in some other manner, so that it may touch the enclosure as much as possible, as in the figure B C D E F G H I K L: if the enclosure or boundary is very irregular, and full of retreats or sinuosities, as the lower part of the plan, their exact plan must be taken independently: then remark where the two cords of the artificial boundary form an angle, as at G, and stretch another cord B V, through the middle of the angle, to the undulations of which measure the length; then stretch cords from the sides of the angles to the undulations, at right angles to the sides, the length of which must be written down, as well as their distances from each other. If the artificial boundary whose plan is required has towers, or other projections, they must be surrounded by cords, and the length of their sides and angles figured down, that their circumference may be defined: to lay such a plan on paper, draw a circle of any length or divisions, as 180 feet: place on one of the sides the length BC, 180 feet; draw with a protractor from the point C, the angle B C D, 101°: continue to draw in succession the length of the sides and angles, until you have the measurement of the whole of the artificial boundary.

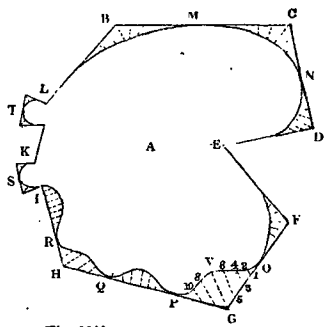


Fig. 1109.

To have the Circular Boundary, observe at what distance from the angles the real boundary touches the lines shown by the cords, as at the points M, N, O, P; then take from the scale their relative distances, and mark them on the sides of the artificial boundary, through which the real outline must be traced.

To have the Circular Boundary correct, observe that the angles of the artificial boundary are divided into two by a right line drawn from the angle to the boundary, the length of which is figured; this must also be set out on the paper at the respective angles: remark also, that to the right and left of each angle of the artificial boundary, where cords are stretched, their distance and length must be set down; and when these lines are properly laid down, the natural boundary may be traced through them.

To trace on the Ground a Plan drawn on Paper.—Having drawn on paper the plan to be laid down, the angles of which are indicated by the letters B C D, E F G, H I K: drive a stump into the ground at the point where it is intended to have one angle of the plan, as at L, where a cord L M must be stretched, towards the place intended to trace the plan; on the line set off L M, 52 feet from L to M, answering for the 52 feet from B to C; and at this point N, drive a large stump into the ground; above the large stump or piquet, place a demicircle with its diameter in the line L N, for the purpose of forming the angle L N C, 123°, equal to B C D on the paper, setting off also 36 feet from N to P, the length of C D: drive another stump into the ground at P, and stretch a cord horizontally between the two piquets P and N; drive other stumps between the two, and mark the two lines forming the angles on the head of each stump: at the point P draw a re-entering angle N P Q, 105°, to equalise C D E, and set off 86 feet on P Q, from P to R, answering to D E on the plan; and continue in the same manner to form the angles, R F N, R S T, S T L, &c., according to the plan, with the lengths of their sides: when there are re-entering angles on the plan, take care to observe if the sides of the plan on the ground agree with those on the paper, which may be rectified by means of fixed points; for example, if the side R S was prolonged, it would exactly fall on the side T V, at the distance of 15 feet from V in L, as is marked from H to X, on the side H G of the plan; if it falls near T, some of the sides or angles are too small, if near V the contrary is the case.

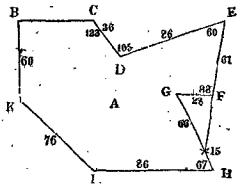


Fig. 1110.

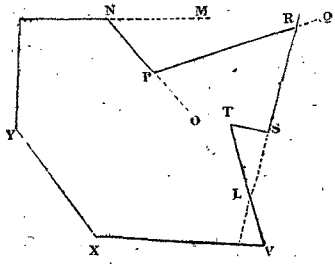


Fig. 1111.

Drawing and measuring Angles on the Ground by a divided Port Crayon and two Cords.—The divided port crayon may be of any length, from 5 to 6 inches, and ¼ of an inch square; the longest are the most convenient, on account of the two equal and parallel lines engraved on them: the line B C must be divided into 180 equal parts, according to the line of chords on a sector; and D E, which is parallel to it, and of the same length, should be divided into 60 equal parts: the two cords may be made of fine twine about 36 feet long, as F, G, H, which must be divided into two at G, and a ring attached there; and also its two extremities, F and H, made large enough to receive a small stump; divide F G and G H each into 30 equal parts to serve as feet, &c.: the second cord F I, which is longer than the first, must be divided into 60 parts, equal to those on the other cord. To draw an angle on the ground, as one of 40°, at fig. 1115, plant a stump at the point where the angle is to be drawn, pass the ring G of the cord over the stump, stretching the side F G towards the place it is required to fix one side of the angle, and drive a stump through the ring F; then remark the port crayon on the line of chords B C, where 40° coincides with the line D E, divide into 60 equal parts; having observed that it is at the 21st, stretch the cord F I, until its 21st point touches the ring H, where a stump must be driven; so that on taking up the cord the stump F G H remaining, the three points of the required angle are given.

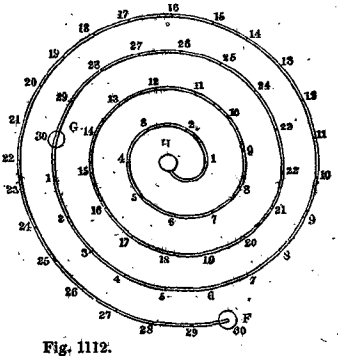


Fig. 1112.

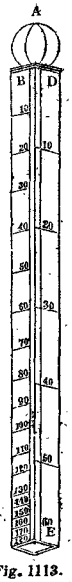


Fig. 1113.

One cord may be considered as passing the whole length of the spiral figure, its first ring at H, its second at G, and a third at the extremity, F, comprising 60 feet: the other cord containing 30 feet, or half the former quantity, has one ring at H and the other at G; by the application of these two cords angles may be set out on the ground: sometimes, instead

of the port-crayon a flat piece of brass or wood is divided longitudinally into two columns, called B C and D E; the first is marked with the 180 degrees, as taken from the line of chords on a sector; and on D E are arranged the 60 equal parts; when these columns are placed side by side it is more easy to read them off.

This instrument is now seldom made use of, but in France it was much employed, and considered sufficiently accurate for all ordinary surveys, or for setting out angles either salient or re-entering: spiral lines were frequently set out with it, and the gardener employed under Le Nostre marked out the fanciful forms which were then in fashion with this simple instrument.

To measure salient and re-entering Angles, as that of the angle L M N, drive a stump at M, over which place the ring G, straining F G and G H against the sides of the angle, and drive a stump into each of the rings F and H.

Stretch the cord F I, which must be attached to the stump F, until it touches the extremity H of the cord F G H, and remark how many divisions of the cord F I there are from F to H; then note on the line D E of the port crayon what division or degree of the line which answers to 50, as 112, which will be the required angle. To find the salient angle O P Q, either prolong O P to R, and Q P to S, to form the re-entering angle R P S, which may be measured by the preceding rule; or place the ring G of the cord at the salient angle P, and stretch the side G F along Q P, and G H along O P, of the salient angle O P Q; so that by measuring with the divided cord the distance F H, number of divisions are obtained, which sought on the line of cords denote the degrees of the angle R P S, as well as the salient angle O P Q, which is equal to it.

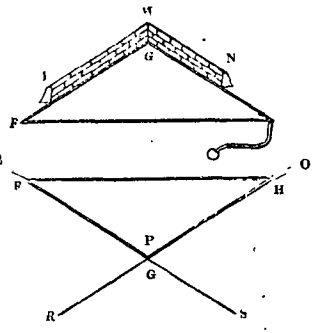


Fig. 1114.

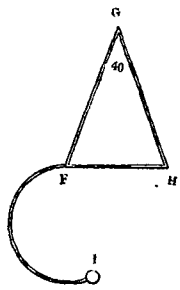


Fig. 1115.

To reduce or enlarge a Plan on a given scale without using a scale or protractor: as, to reduce the plan A, which has for its base F E, to another plan having the base H I. Draw a line K L, and from the point K as a centre, with the base F E as a radius, describe an arc N M, on which set off the given base H I from N to O, and draw a right line K P through O: take the distance F G from the plan A, and describe from the point K, an arc Q R, of which take the chord R Q, and from the point H of the given base, describe with this distance the arc S: from the plan A take the distance E G, and from the point K describe the arc T V, of which take the cord V T, and carry to the point I of the given base H I; and from this point I describe the arc X, which will cut the arc S in Y; from the point H, draw a right line H Y to the point Y, which will make the side H Y homologous or relative to F G, on the plan A: to have the side relative to G B, it is only necessary to follow the same rule, that is to say, from the point K, with the distance G B, describe the arc *a b*, and carry its chord *b a*, to the other point Y, the extremity of the line H Y, and from the point Y describe the arc *c*; then take the distance E B, from the plan A, and with it describe an arc from the point K; so that by taking its chord *e d*, from the point I of the given base an arc may be described, and observing where the arc cuts *c*, as at *g*; then draw the line Y*g*, which will be homologous to G B. All the other relative sides may be found by the same rules, so as to reduce the plan A to another whose base is H I; by this means, plans may be diminished or increased, provided the base is not double the other.

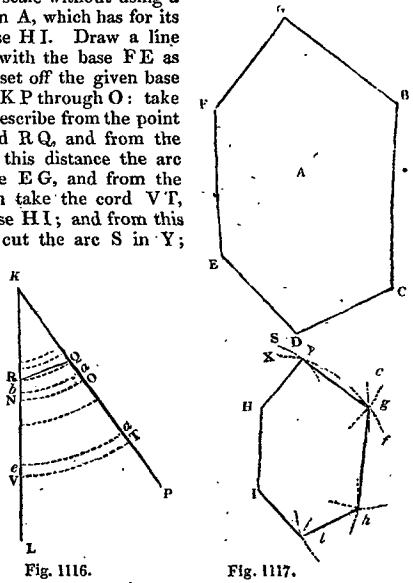


Fig. 1116.

Fig. 1117.

To draw by means of a Scale and Protractor a Plan, greater, equal, or smaller than a given Plan.—It is required to copy the plan A, which is bounded by six sides, B C, D E, &c.; the scale H being divided into 100 parts of the same size. Draw a scale K of the same length as H, viz. into 100 parts; measure how many parts of this are contained by the side B C, as 80; draw the line L N, on which set off 80 parts, as taken from the scale from L to N: then with the protractor measure the angle C B G of 117°, and draw another equal to it at the point N, having its diameter along L N, and count 117 degrees on its circumference, beginning at L: having removed the protractor, draw the right line N P, off 60 equal parts, to answer to the side B G: at the point P draw the angle N P Q equal to B G F on the plan A, and set off as many parts on P Q as are equal to G F on the plan A: continue to draw the relative sides and angles of the plan A, until you have the plan L N P Q R S equal to it.

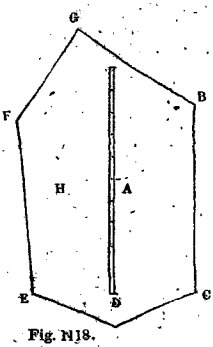


Fig. 1118.

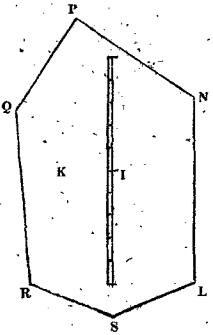


Fig. 1119.

Copying Plans by means of Squares.—To copy the plan A, it may be inclosed in squares, as H I K L: divide the two opposite sides H I and K L into the same number of parts, as into five, and draw right lines through the opposite points of these two lines: divide also the sides H L and I K into any number of parts, and draw lines through the opposite points, which crossing the first will form several squares. To copy the plan A precisely the same size, draw the squares equal, and then tracing the map or plan through all the corresponding parts, they will be alike.

If it be required to copy a plan without drawing, squares on the originals or on the copy, fine threads stretched across may be made to answer the same purpose, and on the paper on which the drawing is to be made, fill up the squares in the manner of the original: thus the copy may be completed without ruling any lines on the original.

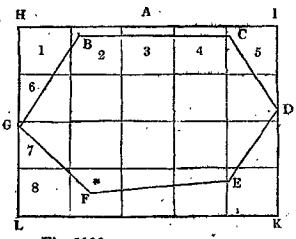


Fig. 1120.

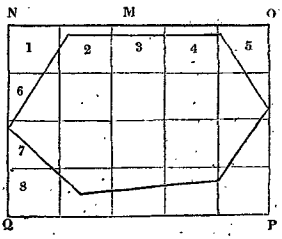


Fig. 1121.

The Cross Staff is commonly of copper or brass; there are both simple and compound: the simple one, A, is a circle of brass, 4 or 5 inches in diameter, divided by two lines at right angles, which have their extremities mounted with sights; the space between the arms is hollow, to render it lighter, and more portable; below the cross is fixed a joint with a dowel to fit into a socket joint, fixed on the staff which supports it.

The cross staff, F, is compound, 6 or 8 inches in diameter; it has four sights, and an alhidade is fitted to its centre by a two-headed screw, as K L, whose extremities

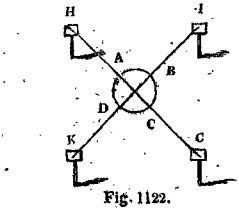


Fig. 1122.

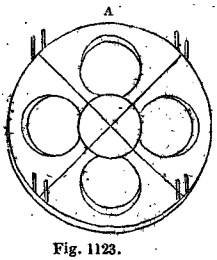


Fig. 1123.

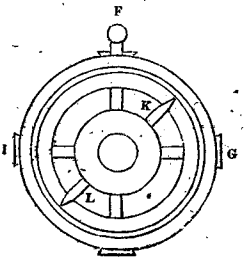


Fig. 1124.

are charged with sights, and work on a circle described on the cross, which is divided into 360 degrees. This alhidade serving to form angles has a magnetic needle at its centre, to mark the point of the compass, by placing one side of the square against the object to be taken. When the double cross has not an alhidade, four more sights are screwed in the intervals of the others, so that the cross has eight sights: it is to be remarked that large squares are to be preferred to small, as they direct the visual rays better.

To ascertain whether the cross staff is accurate, mount it on its stand, and plant it on a level piece of ground; then, boning by the sights A C, place a piquet with its card in the line with the visual ray; and, without removing the cross staff, bone through the sights C, A, and plant a piquet H in the visual ray; bone through all the other sights, and if they cut the same points, as well as the piquets placed at right angles, it may be considered correct.

To measure acute-angled Triangles.—Let fall from an angle of the triangle a perpendicular to the side opposite the angle, and multiply this perpendicular by the length of the side opposite the angle; half the product will give the content or superficies of the triangle required. To measure the acute-angled triangle A B C, plant piquets at A B C, and place the cross staff at some point on the side B C, so that by looking along the sights of one diameter, the two piquets B and C may be seen, and without removing the staff, look also at the piquet A, through the sights of the other diameter; if at D it cannot be seen, the staff is too far to the right, and must be advanced to the left, as at E; then from the point E the two piquets B and C may be seen through the two sights of the diameter, which is in a line with B C, and through the other sights the piquet A; measure the perpendicular E A, which is 24 feet, and B C 52: then multiply the length E A, 80 feet, by B C, 52, and take half the product 4160, we have 2080 superficial feet for the content of A B C, the acute-angled triangle.

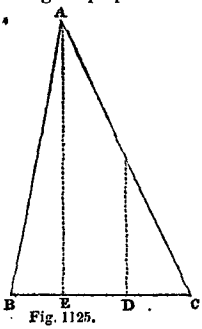


Fig. 1125.

To measure right-angled Triangles.—Multiply the two sides which form the right angle together, and half the product will be the superficial content. Measure the side B C, which is 144 feet 5 inches, and A B 125 feet; multiply 144 feet 5 inches by 125 feet, and the product 18104 feet 6 inches divided gives 9052 feet 3 inches for the superficial content. For if a parallelogram and triangle be upon the same base, and between the same parallels, the parallelogram will be double the triangle, as shown by Euclid in his 41st prop. Book I. It is very manifest that triangles are the halves of parallelograms upon the same base, or upon equal bases and between the same parallels: and because these parallelograms are equal to one another, the triangles which are their halves are also equal: on this account it is said that the rectangle is equal to the product of its base and altitude, and the triangle to half the product of its base and altitude. When the two straight lines which form a rectangle are of such a length that one contains exactly the same number of feet or divisions that there are in the other, or side adjoining it; then the rectangle under these two straight lines is contained as many times in the given rectangle as is expressed by the product of the two numbers, which denote how often the feet or divisions are contained in the two sides.

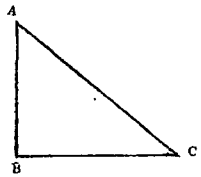


Fig. 1126.

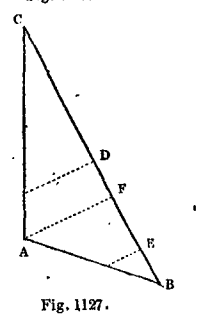


Fig. 1127.

To measure obtuse-angled Triangles.—After having planted piquets at the three angles A, B, C, place the cross staff at some point on the side B C, as at D, in such a manner that by looking along the sights of one diameter, the two piquets B and C are seen, and by those on the other diameter the piquet A; if the piquet is not seen, the square is not exactly opposite the angle A, and must be advanced to F or E. Then measure the perpendicular F A, which is 220 feet, and B C 663 feet, which multiplied produces 145860, the half of which, 72930, feet is the superficial content required.

To measure inaccessible Angles.—First find by the trigonometric rules the length of the sides of the triangle, viz. A B 68, B C 70, C A 28, and draw a similar triangle D H E; raise a perpendicular on the side D E, as H G, and proceed as before described.

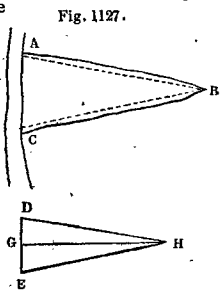


Fig. 1128.

To measure any Triangle, as that of A B C. Multiply the length of B D, the perpendicular, by the base A C, and half their product will be the area: this will be evident if we observe that in measuring the square we multiply the two sides which form a right angle together; the product will be the area of the square, as that of A B C D.

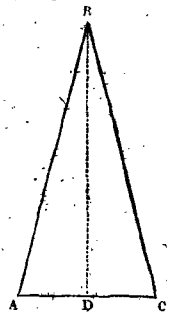


Fig. 1129.

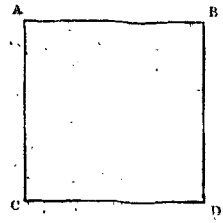


Fig. 1130.

In any triangle the difference of the squares of the two sides is equal to the difference of the squares of the segments of the base, or of the two lines or distances included between the extremes of the base and the perpendicular. Let A C B be any triangle, having B D perpendicular to A C, then will the difference of the squares A B, B C be equal to the difference of the squares of A D, C D; that is, $AB^2 - CB^2 = AD^2 - CD^2$.

For since AB^2 is equal to $AD^2 + BD^2$,
and CB^2 is equal to $CD^2 + BD^2$,
therefore the difference between AB^2 and CD^2
is equal to the difference between $AD^2 + BD^2$,
and $CD^2 + BD^2$,
or equal to the difference between AD^2 and CD^2, by taking away the common square BD^2.

The rectangle of the sum and difference of the two sides of any triangle is equal to the rectangle of the sum and difference of the distances between the perpendicular and the two extremes of the base, or equal to the rectangle of the base and the difference or sum of the segments, according as the perpendicular falls within or without the triangle.

To measure Rhomboidal Figures.—Let fall a perpendicular from one angle to the opposite side, and this perpendicular multiplied by the side gives the area required; but when this cannot be done, prolong one side; let fall a perpendicular on the side of the rhombus, and proceed as before.

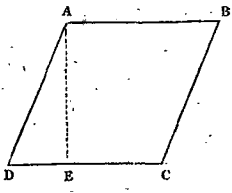


Fig. 1131.

For example, to measure the rhombus A B C D, whose side A B is 30 feet long; as this figure has no right angle, it is necessary that one should be established; this is effected by placing the cross staff on C D, in such a position that a piquet at A may be seen through one of the pinnules on one diameter, and D C through those of the other, as at E; then measure the perpendicular, 27 feet, which multiplied by 30, the length of the side A B, produces 810 feet as the superficial area of the figure A B C D.

To measure a Trapezium.—Add together the two parallel sides, and multiply their sum by the length of a perpendicular line contained between their two sides, and which is the height of the trapezium; the product will give the area.

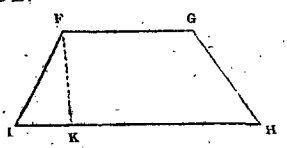


Fig. 1132.

To ascertain the content of the figure F G H I, where the two sides F G and I H are parallel, the shortest being 30 feet 9 inches, and the longest 60 feet: place the cross staff on I H, as at K, so that through the pinnules of one diameter the piquets I and H may be seen; then through the other view the piquet F, where K L, which is 20 feet, is the perpendicular. Add together the two parallel sides, which will be 90 feet 9 inches; this multiplied by 20 will produce 1815 square feet, the half of which will be the area sought.

To measure the Trapezoid M N O P, whose side M N is 4 feet. Plant piquets at the four angles: draw from the angle P the diagonal P N, which will divide it into two triangles; find their superficial content, and add them together for the area of the trapezoid. For example, find the area of the triangle P N M, the base of which, P N, is 6 feet 6 inches, and the perpendicular R M 2 feet; these multiplied together produce 13 feet, the half of which, 6 feet 6 inches, is the area of the triangle; proceed in the same manner for the area of the other part of the figure, and add them together.

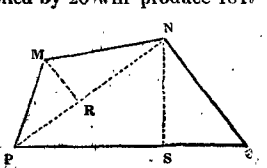


Fig. 1133.

To measure a regular Polygon. — Add all the sides together, and multiply the sum by a perpendicular let fall from the centre to one side; half the product will be the area.

To find the superficial content of the pentagon ABCDE, measure one side DC, which is 22 feet, and then multiply it by 5, the number of the sides: multiply its product 110 by 15, the height of the perpendicular FG; take half this product of 1650, which is 825 superficial feet, for the area.

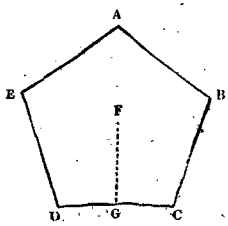


Fig. 1134.

When the figure is inaccessible, surround it by the square or rectangle FGHI, whose side FG is 35 feet 3 inches, and FI 33 feet 6 inches 4 parts; when these two sides are multiplied together, their product will be the area of the rectangle: then measure the four triangles FAE, AGB, EDI, and BHC; when their areas are found and added together, deduct the sum from that already found for the whole rectangle, and the remainder will be the area of the pentagon. Similar polygons inscribed in circles have, as we have already seen, their perimeter in the same ratio as the diameters of those circles; for if we imagine the number of sides to be infinite, or so numerous that they coincide with the circumference of the circle, then the perimeter of such a polygon may be regarded the same as the circumference of the circle.

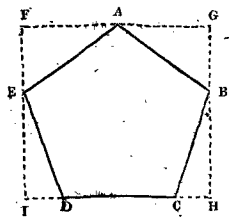


Fig. 1135.

To measure an irregular Polygon. — Plant piquets at all the angles of the irregular polygon, and one in the centre of the figure, in order that cords may be stretched from thence to the angles; by this means the irregular figure will be divided into triangles, which may be measured separately, and the whole added together.

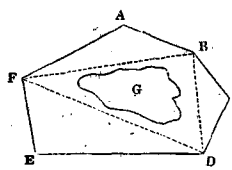


Fig. 1136.

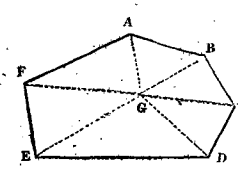


Fig. 1137.

To measure the irregular hexagon ABCDEF, plant piquets at all the angles, and one in the centre; then stretch cords to the several angles, and when they are defined the lengths of their sides may be obtained, and their areas found, which added together will be that of the whole.

If the hexagon ABCDEF has a piece of water in the centre, and is inaccessible, then cords may be stretched from opposite angles, and by this means measured, and the area found. If the entire area is inaccessible, then the whole figure may be bounded by a rectangle, and all the outer angles measured.

In measuring land, take as few dimensions as possible; measure, for instance, FC, and drop perpendiculars from A, B, D, E, and measure them. If the figures are very irregular, as GHIKLMNOPQRSTVX, form it into trapeziums and angles.

It must always be borne in mind that a vast number of small figures tend to confuse the surveyor and render his calculations more difficult; it is therefore advisable not to have a greater number of triangles than is absolutely necessary, for in finding their area it is impossible to avoid

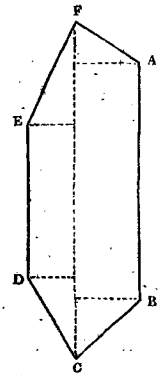


Fig. 1138.

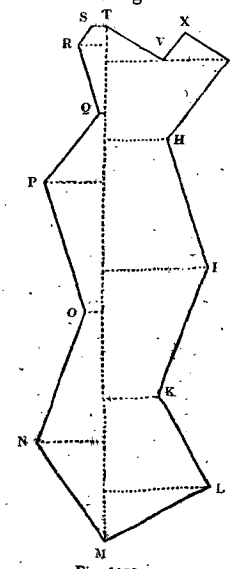


Fig. 1139.

fractions or decimal quantities, which, when added or taken away, often materially affect the whole quantity.

To measure the Circle.—This cannot be done in any other manner than by approximation, as we cannot find the quadrature of the circle, or the superficial content of a square, which shall contain precisely that of a given circle. If a triangle A has three equal sides, each 14 feet 8 inches long, its circumference will be 44 feet: if the square B has each of its four sides 11 feet long, its circumference will be 44 feet; and if the circle C has its circumference 44 feet, these three figures will be isoperimetrical. If you measure the triangle A and the square B by the rules given already, you will find that the square contains 121 feet superficial, the triangle 45 feet 4 inches, and the circle 154 superficial feet. Of all who have written on the subject, none have given rules which approximate nearer to truth than Archimedes; he states the circumference of a circle is 3⅐ the diameter, that is to say, the circumference A B C D will be 22 feet if its diameter A C is 7 feet, so that the diameter is to the circumference as 7 to 22, and the circumference to the diameter as 22 to 7. This is shown in the circle A B C D, which, reduced to a straight line, as A F, is three times the diameter A C, and ¼ of F E.

The second approximation is that the area of a circle is equal to a right-angled triangle formed of the circumference and radius of a circle; that is to say, the right-angled triangle G I H contains the same area as the circle K, because the triangle has its side H I equal to the circumference of a circle, and G H, which forms a right angle with it, equal to the radius G K. The other supposition of this great mathematician is, that the superficies of a circle is to the square of its diameter as 11 to 14; that is to say, if the circle M contains 11 superficial feet, the square H P O N drawn on its diameter will contain 14, and it will be seen that the circle Q, inscribed in the square R S V T, is less than the square by a certain quantity.

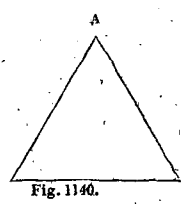


Fig. 1140.

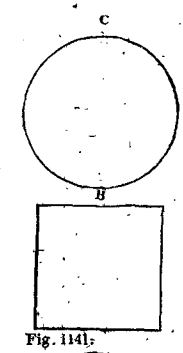
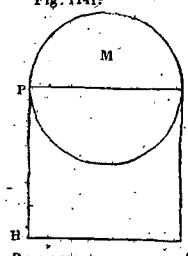


Fig. 1141.



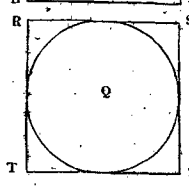


Fig. 1142.

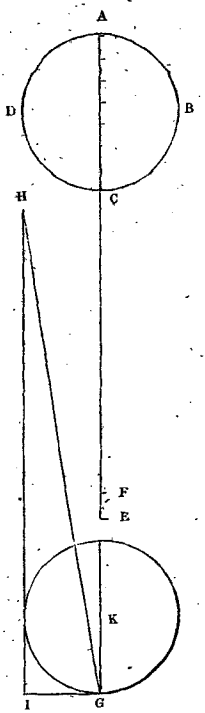


Fig. 1143.

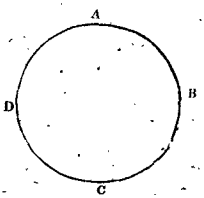


Fig. 1144.

The relation of 7 to 12, which Archimedes gives as the ratio of the diameter of a circle to the circumference, holds good with a greater number of figures, as of 100 to 314, and the larger the number of figures the nearer is the truth approached.

To find the Circumference of a Circle when the Diameter is given. By proportion, place in the first term 7, in the second 22, and in the third the length of the diameter: the quotient will give the circumference. If we require the circumference of the circle A B C D, according to Archimedes, we should place for a first term 7, for the second 22, and for a third the length of its diameter; the quotient would be the circumference sought: if the diameter be 15 feet for instance, then, 7 : 22 :: 15 : 47 ft. 1 in. 8 p.; or, 100 : 314 : 15 : 47 ft. 1 in. 2 p.

To find the Diameter of a Circle when the Circumference is given. Place in the first term 22, in the second 7, and in the third the known circumference, and the quotient will be the diameter.

To find the Area of a Circle when the Diameter is given. First find the circumference, and

multiply it by the radius, and half the product will be the area: or, multiply the square of the diameter by ·7854, and the product is the area.

To find the Area of a Circle when neither the Diameter nor the Circumference are given. When the arc E C F is given, to find the area of the circle A B C D: draw the chord or right line E F, and divide it into two equal parts, from whence draw a perpendicular G C, and measure F G; then multiply E C by itself, and divide the product by G C; the quotient will give E G, to which add G C; the sum will be the diameter A C: then by proportion proceed as before described.

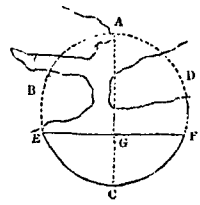


Fig. 1145.

To measure a Circular Ring, as A B C D.—First ascertain the area of the whole circle, and then of the part contained in the lesser one, and deduct one from the other; the remainder will be the area of the ring.

The diameter of the interior circle we will suppose 9 feet; its circumference then will be found to be 28 feet 3 inches 5 parts; and if we consider the breadth of the circular ring to be 3 feet, we shall have 15 feet for the diameter of the outer circle, the circumference of which will be 47 feet 1 inch 8 parts; the arc of this circle will be found equal to 176 feet 3 inches: if we then deduct from it the area of the inner circle, we shall obtain superficial content of the circular ring.

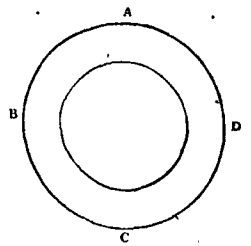


Fig. 1146.

The areas or spaces of circles are to each other as the squares of their diameters or of their radii, for, as before observed, similar polygons inscribed in circles are to each other as the squares of the diameters of the circles; for, conceiving the number of sides of the polygons to be increased more and more, or the length of the sides to become less and less, the polygon approaches nearer and nearer to the circle, till in the end it coincides and becomes in effect equal; hence the areas of circles, which are the same as polygons, must be to each other as the squares of the diameters of the circles.

To find the Area of a Spiral.—Add together the exterior and the interior circumference, and multiply their sum by the breadth of the band, and half the product will be the area. To measure such a spiral as A, whose breadth B H is 3 feet, its exterior circumference B C D 25 feet 1 inch 8 parts, and its interior 15 feet 8 inches 7 parts; add these together, and multiply their sum, 40 feet 10 inches 3 parts, by 3 feet, the product of which divided will give the area of the band.

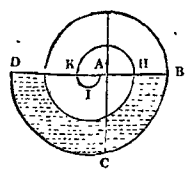


Fig. 1147.

To find the Area of Sectors.—Multiply the arc C D E by B C, the radius of the circle; take half the product, which will be the superficial content of the section. By the same rule the area of the sector X may be ascertained; for example, to measure the figure A, we multiply the arc C D E, 15 ft. 8 in. 6 p., by D C 7 ft. 6 in. which is the radius of the circle. Half the product will be the content of the segment; and if, on adding the area of the sector X, we find the sum equal the content of the whole circle, we are sure that the calculation is correct.

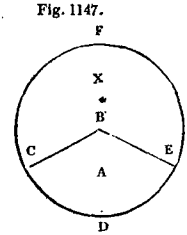


Fig. 1148.

The sector of a circle is a portion of the area of the circle bounded by two radii and the intercepted arc, and sectors are said to be similar when the sides or radii include equal angles. The area of a sector, then, must be equal to that of a triangle whose base is equal to the length of the contained arc, and altitude equal to the radius of the circle.

To find the Area of a Segment.—Form on the arc C D E a sector B E D C, and find the area by the preceding rules; then find the area of the triangle, and subtract it from the area of the whole; the remainder will be the area of the segment. For example, the line C E, 12 feet 5 inches 8 parts, and its arc C D E, 12 feet 8 inches 6 parts, to ascertain its area: form on the arc C D E the sector B E D C, and find its superficies; then that of the triangle B E C, and subtract it from the area of the whole sector, when the remainder will be that of the segment A. Should the segment be small, add half the length of the chord to $\frac{3}{4}$ the height of the arc, and multiply the sum by the whole height of the arc.

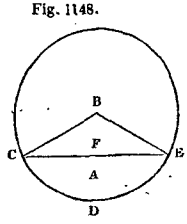


Fig. 1149.

To find the Area of an Oval.—Multiply the length of the greater diameter C D by the lesser E F; their product will serve for the third term, whose first is 14 and second 11; the quotient will be the area sought: or, multiply the two diameters together, and their product by 785, which divided by 1000 gives the area: or, multiply the two diameters together, and extract the square root, which will be the diameter of a circle whose area is equal to that of the ellipsis.

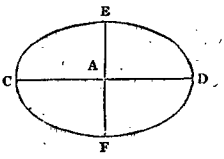


Fig. 1150.

To find the Area of a Sphere or Globe.—Multiply its circumference by the diameter; the product will be the superficial content; or, the surface of a sphere is equal to the diameter squared, multiplied by 3·141593, and the surface of a spherical segment is equal to the circumference of the sphere, multiplied by the height of the segment: the sphere is a solid bounded by one curve surface, which is everywhere equally distant from the centre; it may be conceived to be generated by the rotation of a semicircle about its diameter, which remains fixed: the axis of the sphere being a right line about which the semicircle revolves, and the centre the same as that of the revolving circle.

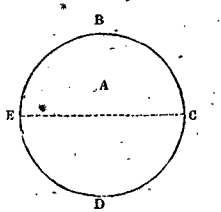


Fig. 1151.

Archimedes gives another rule for finding the superficies of a globe, which is that of multiplying the superficies of their great circles by 4; thus in the globe A the area of its greatest circle is 176; this multiplied by 4 gives 704 for the superficial content. The diameter squared, its product multiplied by 314, and then divided by 100, the quotient will be the superficies of a sphere.

There are some peculiar properties belonging to spheres; for two will cut one another, or touch one another, or one of them will fall wholly without the other, according as the distance between their centres is, *first*, less than the sum, and greater than the difference of their radii; secondly, equal to the sum, or to the difference of their radii; or thirdly, greater than the sum, or less than the difference of their radii; for the sections of two spheres made by a plane passing through their centre, and through any point which is supposed to be common to the two surfaces, will be circles having the same radii and centres with the spheres respectively. If two spheres cut one another, they do so in a circle, the plane of which is perpendicular to the line joining their centres, and its centre is that line. If three spheres be described whose centres do not lie in the same straight line, the surfaces of the three cannot have more than two points in common, which points lie in a straight line perpendicular to the plane of the centres, and at equal distances on either side of that plane. If the centres of three spheres lie in the same straight line, their circles of intersection cannot meet one another, because their planes are perpendicular to this straight line, and therefore parallel: and accordingly, the surfaces can have no point in common, unless each of them passes through the same point of the straight line in which the centres lie, for then each of them will touch the other two in that point. When a point is equally distant from the three angles of a triangle, it must lie in a perpendicular to the plane of the triangle, which passes through the centre of the circumscribing circle.

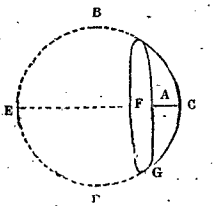


Fig. 1152.

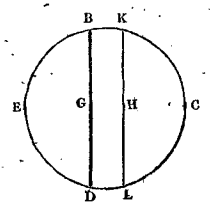


Fig. 1153.

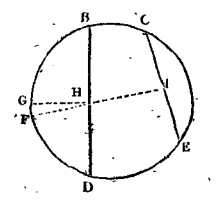


Fig. 1154.

To find the superficial Content of Segments of Spheres.—Multiply the circumference of the entire sphere by the axis A of F G for the area.

To measure the superficies of regular zones, as of B K D L, we must multiply the circumference by the height of the segment.

The superficial content of the irregular zone B C E D may be also found by ascertaining, first, those portions which are of a regular breadth, and then those which are not.

Suppose it is required to ascertain the superficial content of the zone B C D E, the diameter of which is 15 feet, and the greatest circumference 47 feet 1 inch 8 parts. If we follow the rules already laid down, we shall find the area of the great segment C E F, which is formed from the segment B D G, and the irregular zone B C E D, by multiplying the circumference of the globe B C E D F G by the length of the part of the diameter F I comprised within the great segment C E F, which will give 565 superficial feet for its content. Then, after subtracting the superficial content already found, of the smaller segment B D G from that of the great segment C E F, there will remain 329 superficial feet for the area of the irregular zone B C E D, which surrounds the globe.

To find the Superficies of Cones, it is only necessary to multiply the length of the side by the circumference, and take half the product. Thus in the cone A, whose side B E is 24 feet, and the circumference of the base BCD 19 feet, $24 \times 19 = \frac{456}{2} = 228$. To measure the superficies of the truncated cone A, whose diameter at the base B E is 8 feet, and at C G 6 feet: add together these diameters, and take the half for a mean, which is 7 feet; this multiplied by 8, the length of the side BC, gives the product 56, from which the square root is to be extracted.

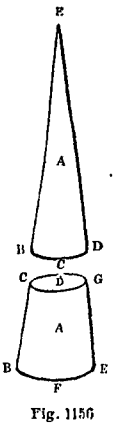


Fig. 1156

It must be borne in mind that with a radius of 7 feet 6 inches, which is equal to H I, we can describe a circle H K L M, which shall contain an area equal to the superficies of the cone A.

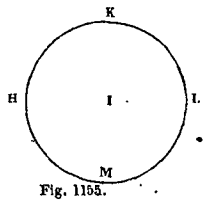


Fig. 1155.

To find the Area of a Cylinder.—Multiply the height by the circumference; the product will be the area, to which add that of the two ends.

To measure the cylinder A, multiply the height B C, which is 21 feet, by the circumference C D E, which is 44 feet, and the product, 924 feet, will be the superficies of the cylinder, without comprising the area of the two ends.

If the cylinder be irregular, as that at F, multiply the less height, I K, 13 feet, by the circumference, G H I, 44 feet, and the product will be 572. Subtract the shortest height, I K, 13 feet, from the longest, G L, 21; multiply the remainder, 8, by the circumference, and take half the product, 176, and add it to 572, which will be 748, the superficies of the cylinder.

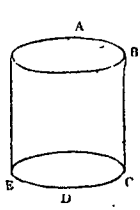


Fig. 1157.

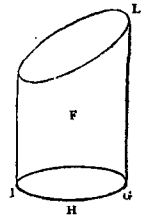


Fig. 1158.

Mixed or irregular Figures, as ovals or parabolas, must be divided into small segments, triangles, and squares before their area can be ascertained. The oval shown at A for instance may be divided into two segments, B C F and B C G, and the area found by the preceding rules.

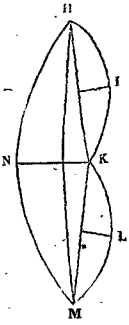


Fig. 1159.

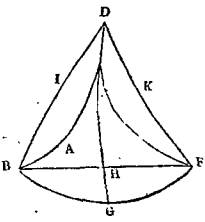


Fig. 1160.

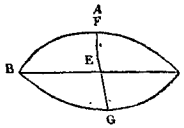


Fig. 1161.

Figures bounded by several curved lines must be enclosed within a triangle, as that at F D B G, by the lines I and K: the area of the equilateral triangle being found, the segments may be afterwards found, and their area deducted: when the form is very much varied, as that comprised within the irregular line H I K L M N, it must be similarly treated, dividing it into triangles, segments of circles, or any other regular figures.

On flat and round Superficies.—We at once see in the diagrams G and H the effect of houses so placed that they radiate from a centre, and are drawn perpendicular to the base line. On hilly or mountainous land no more grass or trees can grow than would do on its base if the whole were levelled: trees rise perpendicular, or tend to the centre of the earth, and not to the surface on which they stand; consequently the superficial content or area of a mountain is that of its base; so it is with a field, where no more blades of corn can stand upon uneven ground than would on the level plane comprised within the same boundary. In carrying a fence

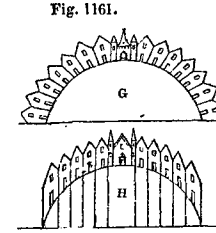


Fig. 1162.

over a hill composed of upright paling, we shall discover that, although more rails might be required to pass over the convex surface, as there are more houses shown on G than on H, there would not be more posts or upright pales.

The conversion or reducing of Plane Figures of one kind to that of another is found extremely useful in practice, as it often saves considerable trouble in the calculation, particularly where they are very irregular: this subject has not received the attention it demands in the ordinary works which treat upon the measurement of land.

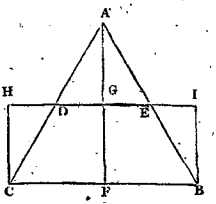


Fig. 1163.

To reduce a Triangle to a Rectangle.—If the triangle be equilateral, as A B C, and it is required to form a rectangle on the side C B; divide the other two sides A C and A B into two equal parts in the points D and E; through them draw the line D E, parallel to the side C B: from the point A drop a perpendicular A F to C B; remark where it cuts D E at G; set off D G from D to H, and E G from E to I; draw the right lines H C and I B: the parallelogram H I B C will be equal to the equilateral triangle A B C on the given side C B.

To reduce a Rectangle to a Triangle, as the figure A B C D to an isosceles triangle. Bisect the base D C of the square in E, and elevate a perpendicular E F, twice the length of the side of the square; draw the upright lines F D and F C; the superficies of the isosceles triangle will be equal to that of the square.

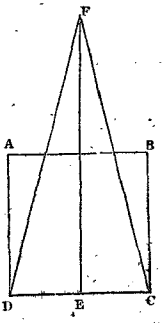


Fig. 1165.

If it be required to reduce the parallelogram G H I K to a scalene triangle, it is only necessary to divide the base of the parallelogram into two unequal parts, as at L, and elevate a perpendicular L M, twice the length of the side of the square; then draw the right line M K and M I: the superficies of the scalene will be equal to that of the rectangle.

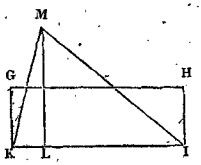


Fig. 1164.

To elevate or depress a Triangle on a given length, without altering its superficial content, as to elevate the point A of the triangle A B C, so that it may be at the distance D E from the base C B. Draw a perpendicular to the base C B, through the point A, and set off the given length from F to G, and draw a line H I through G at right angles to F G; prolong A C until it cuts H I in K; from this point K draw a right line K B; make A L parallel to K B, and draw the right line K L; the triangle K L C will be equal to A B C.

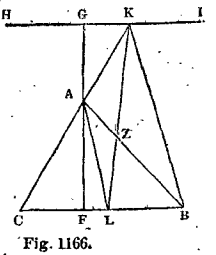


Fig. 1166.

To prove that the triangle K L C is equal to the triangle A B C, and that it is the height of the line given: it must be remarked that the line K L has cut the side A B in Z, and that by its construction the lines K B and A L are parallel, which occasions the two triangles A B L and A K L, which are on the same base A L, and between the same parallels K B and A L, are equal to each other, agreeably to the 37th proposition of Euclid's First Book; so that the triangle A Z L being cut off, the two triangles Z B L and Z K A will remain equal to each other. If from the triangle A B C we cut off the triangle Z B L, to make Z K A equal, we shall have the triangle K L C equal to A B C, and the height of the line already given; since the line H G I, which is parallel to the base C F B, is removed from it the distance of the given line by the perpendicular G F, which is equal to it.

To reduce Trapeziums and Trapezoids to Triangles, as the figure A B C D to a triangle, whose height shall be equal to the trapezium: fix a point in one side of the trapezium, for the summit of the triangle, as E on A B; from this point E draw to the extremities of the base D C the right lines E D and E C, and prolong the line D C either way; from A draw a line parallel to E D, cutting the line in F, and likewise from B draw B G, parallel to E C; draw E F and E G, to have the triangle E F G equal to the trapezium A B C D.

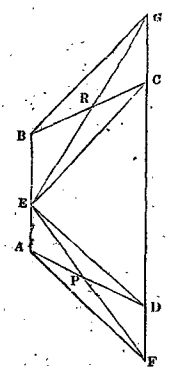


Fig. 1167.

To prove that the triangle E G F is equal to the trapezium A B C D, and of the same height, we have only to observe that the lines E F and F G cut the sides A D, B C at the points P and R, and that by the construction the lines E D and A F are parallel, which causes the two triangles A E D and F D E to be upon the same base E D, and between the same parallels E D and A F.

To reduce Multilateral Figures to Triangles, as the regular pentagon A B C D E to a triangle. Prolong the base D C, and on it set off twice the length of D C to F and G; from the centre H of the pentagon draw the right lines H F and H G: the area of the triangle H G F will be equal to that of the pentagon.

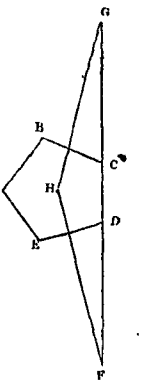


Fig. 1168.

To prove that the triangle H G F is equal to the pentagon A B C D E. Draw from the centre H the two right lines H D and H C; then remark that the base F G of the triangle H G F contains five times the base of the triangle H C D, so that the triangle H G F is composed of five equal triangles according to the 38th proposition of Euclid's First Book: but the triangle H C D is also the fifth part of the regular pentagon A B C D E, so that the triangle H C D being the fifth part of the pentagon A B C D E, it is also of the triangle H G F: then, by the ninth proposition of Euclid's Fifth Book, the triangle H G F is equal to the pentagon A B C D E.

Rectangles, it must be remembered, which have the same or equal altitudes, are to one another as their bases: for if the base of one of the rectangles be divided into any number of equal parts, the rectangle itself will be divided into as many equal rectangles by straight lines drawn parallel to its side through the points of division; also the base of the other rectangle will contain a certain number of parts equal to those into which the first base is divided, exactly or with an excess less than one of those parts, and that rectangle will contain as many rectangles equal to those into which the first rectangle is divided exactly, or with a corresponding excess less than one of them; and this will be the case, whatsoever be the number of parts in the first base and rectangle.

To reduce the Superficies of the irregular Pentagon I K L M N *to a Triangle:* prolong any side of the pentagon on either hand as the base M L: then from the opposite angle to the side M L, as the angle I, draw the right lines I M and I L; from the point N draw N O, parallel to I M, and draw the line I O; the triangle I P O will be equal to the pentagon I K L M N. If the area of the figure be reduced to an irregular hexagon, Q R S T V X, you must prolong one of the sides T S, on either hand, and from the point X draw the line X T, from the point V the right line V Y, parallel to X T, and from the point X draw the line X Y, which, with the four other sides, will form an irregular pentagon, X Q R S Y, from which a triangle may be drawn according to the preceding rule.

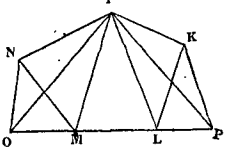


Fig. 1169.

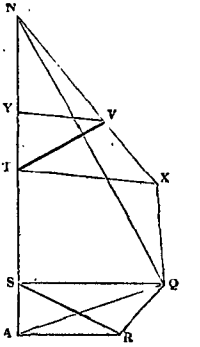


Fig. 1170.

To prove that the triangle I P O is equal to the irregular pentagon I K L M N: it must be remarked that the two triangles I M N, I M O, are equal, because they are on the same base I M, and between the same parallels N O and I M, so that if we take the triangle I M O for its equal I M N, we shall have the trapezoid I K L O equal to the pentagon I K L M N; the triangles I K L and I P L are also equal, so that in placing the triangle I P L for its equal I K L, we have the triangle I P O equal to the irregular pentagon I K L M N.

To reduce an irregular Heptagon, as A B C D E F G, with a re-entering angle to a triangle: prolong the base E F on each hand; draw from the point A a line A F, and from the point C another parallel to it, viz. G H, and draw H H: then from the angle C draw the right line C E, and from D draw D I parallel to it, and then draw C I; from the point B draw B I, and from the point C the line C K, parallel to it, and draw B K; from the point A draw A K and B L parallel to it, and draw A L: the triangle A L H will be equal to the irregular heptagon A B C D E F G.

Any two rectangles are to one another in the ratio which is compounded of the ratios of their sides: this is clearly shown in the 23d Prop. of Euclid's Sixth Book; and it also is made apparent by the same proposition, that any two parallelograms whatever are to one another in the ratio which is compounded of their bases and altitudes, for the rectangles to which they are equal are in that ratio.

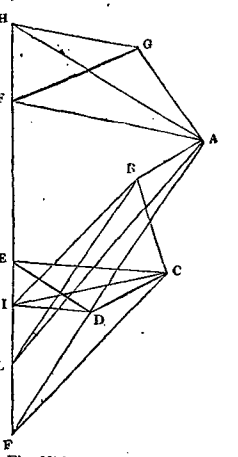


Fig. 1171.

To reduce a Square to a Parallelogram on a given length, as the square A B C D to a parallelogram which shall be of the length E F: prolong the side A of the square, and on it set the given length E F, from B to G, and prolong the other three sides; draw the right line G C till it cuts A D prolonged in H: through the point H draw a line parallel to A G, as H I, and from G draw a line parallel to the side B C I, as is G L, cutting the side C D prolonged in M: then the parallelogram C M L I will be equal to the square A B C D.

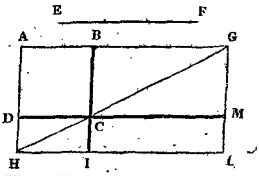


Fig. 1172.

The complements of the parallelograms which are about the diameter of any parallelogram are equal to one another: let H A G L be a parallelogram, of which the diameter is H G; and D I, M B parallelograms about H G, that is through which H G passes; and A C, C L, the other parallelograms, which make up the whole figure H A G L, which are therefore called the complements. The complement A C is equal to the complement C L, because H A G L is a parallelogram, and H G its diameter; the triangle H A G is equal to the triangle H L G; and because D C I H is a parallelogram, the diameter of which is H C, the triangle H D C is equal to the triangle H I C; by the same reason the triangle C B G is equal to the triangle C M G: then because the triangle H D C is equal to the triangle H I C, and the triangle C B L to C M G, the triangle H D C, together with the triangle C B G, is equal to the triangle H I C, together with the triangle C M G: but the whole triangle H A G is equal to the whole H L G; therefore the remaining complement A C is equal to the remaining complement C L.

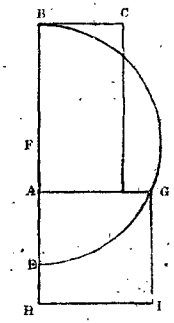


Fig. 1173.

To reduce a Rectangle to a Square. — Prolong one of the long sides of the rectangle, as A B to H, and set off the width A G on it, from A to E: to find a mean proportional between A and A E, divide E B in F, and from the point F, with the radius F H, describe a semicircle: prolong A D till it cuts the semicircle in G: A G will be the mean proportional, and the square A C I H constructed on it will equal A B C D.

To lengthen or shorten a Parallelogram on a given length. It is required to reduce the parallelogram A B C D, to one which shall be of the length E F: prolong the four sides of the parallelogram to infinity, and set off the given length from B to G, and from C to H, and then draw G H parallel to B C: draw the diagonal G C, till it cuts A D prolonged in I, and draw through this point H, a line parallel to D C H, cutting B C prolonged in K, and G H in L; then the parallelogram C H L K will be equal to A B C D.

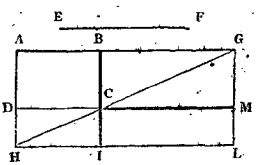


Fig. 1174.

The straight lines which join the extremities of two equal and parallel straight lines towards the same parts are also themselves equal and parallel: let B G and C M be equal and parallel straight lines, and joined towards the same parts by the straight lines B C, G M; B C, G M are also equal and parallel; join G C: and because B G is parallel to C M, and C G meets them, the alternate angles B G C, G C M are equal; and because B G is equal to C M and G C common to the two triangles B G C, M C G, the two sides B G, G C are equal to the two M C, C G, and the angle B G C is equal to the angle G C M: therefore the base B C is equal to the base G M, and the triangle B G C to the triangle G C M, and the other angles to the other angles, each to each, to which the equal sides are opposite: therefore the angle B C G is equal to the angle C G M, and because the straight line G C meets the two straight lines B C, G M, and makes the alternate angles B C G, C G M equal to one another, B C is parallel to G M, and it was shown to be equal to it.

To reduce the Area of a Circle to that of a Square, &c. It is required to reduce the circle H I K to a square: divide the diameter K I of the circle into 14 equal parts, and count off 11 of these parts to L; at this point L, and in K I, elevate a perpendicular L M; remark where it cuts the circle in H, and draw K H; then a square constructed as K H, as is N O H K, will be equal to the circle H I K.

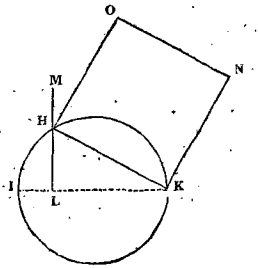


Fig. 1175.

To reduce the Area of a Square to that of a Circle, divide one side of the square, as C D, into two equal parts in E: at this point E, draw E F perpendicular to D C, half the length of D E; from the point F as a centre, with the radius F D, describe the circle D C G, which will be equal to the square A B C D.

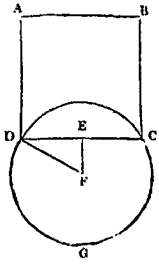


Fig. 1176.

Similar four-sided figures, or of any number of sides, are to one another in the duplicate ratio of their homologous sides, and universally similar rectilineal figures are to one another in the duplicate ratio of their homologous sides, and according to cor. 2. attached to the 20th prop. of Euclid's Sixth Book, if three straight lines be proportionals, as the third is to the third, so is any rectilineal figure upon the first, to a similar and similarly described rectilineal figure upon the second: and the same geometrician teaches us in the 9th prop. of his Fifth Book, that magnitudes which have the same ratio to the same magnitude are equal to one another, and those to which the same magnitude has the same ratio are equal to one another.

To reduce a circle to an Oval on a given Length, as the circle A B C D, to an oval, whose greatest diameter shall be equal to E F; draw a right line G H, and set off the given length E F, from G to I; at the point I elevate a perpendicular I K, of the same length as the diameter of the circle D B: draw the right line G K, and bisect it in L; from L draw the perpendicular L M; from the point N, where it cuts G I, with the radius G N, describe a semicircle G K O, and I O will be the shortest diameter of the oval: then draw the two diameters of the oval at right angles to each other; take the given length E F with a thread, fold it in half, and place the two extremities on the diameter Q R, at the points Y and X, equidistant from V; so that the fold or angle of the thread may coincide with the point S, the width of the required oval; so that by moving a pencil through the points S, R, T, and Q, you will describe an oval equal to the given circle A B C D.

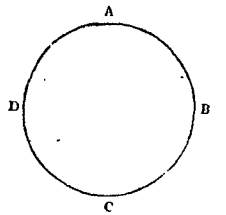


Fig. 1177.

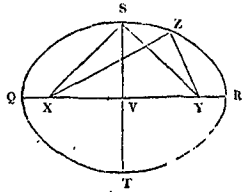


Fig. 1178.

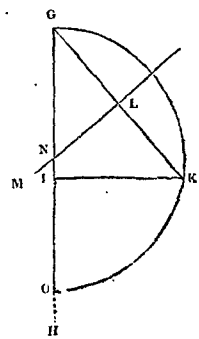


Fig. 1179.

To unite several Figures into One, and increasing the Content of others. — To reduce several figures into a triangle whose height shall be equal to a given height, as that of the triangle A B C, and the square D E F G: draw a right line H I, and on this line at the point H, make such an angle as it is desired the triangle should have, as I H K: take the height A T of the triangle A B C, and draw a line R S parallel to H I; at the distance A T, set off the line C B on H I, from H to M: reduce the square D E F G, to a triangle D N G, and make the triangle D N G equal in height to A B C, as is the triangle O P G; set off the base G P on H I from M to Q, and draw L Q; the triangle L Q H will be equal to the square D E F G, and the triangle A B C.

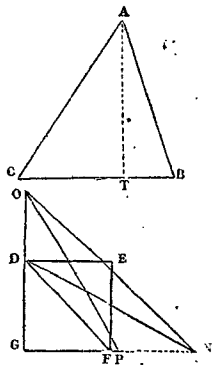


Fig. 1180.

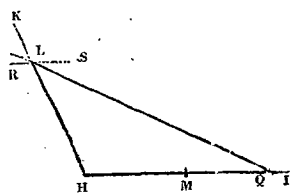


Fig. 1181.

To reduce two Squares into One.—If two squares touch at one angle, and the two sides of one angle are in a line with the two sides of another angle, as at A B G and E B C, draw a right line G C, on which form the square C G H I; its area will be equal to that of the two squares; but if the two squares do not touch, as K L M N and O P Q R, draw a right angle S T V, and set off the side V K L on T S, from T to X, and the side O P on T V, from T to Y; draw the right line X Y, on which erect the square X Y Z, &c., and it will be equal to K L M N and O P Q R.

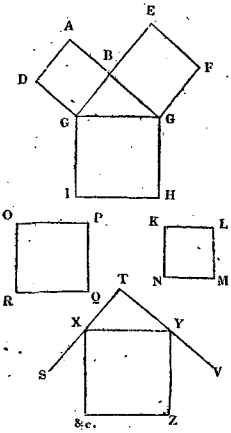


Fig. 1182.

Euclid, in his 47th prop. of Book I. demonstrates, that in any right-angled triangle the square which is described upon the side subtending the right angle, is equal to the squares described upon the sides which contain the right angle.

To reduce a Square into several equal Squares, as that of A B C D into two equal squares: divide one side into two equal parts, as A B, in E; from E with a radius A E, describe the circle A G B: elevate a perpendicular E F from E, observe where it cuts the demicircle, as at G, in order to draw the lines A G and G B; the squares constructed on these lines will contain half A B C D.

In any right-angled triangle the square which is described upon the side subtending the right angle is equal to the squares described upon the sides which contain the right angle. Let G A B be a right-angled triangle, having the right angle A G B; the square described upon the side A B is equal to the squares described upon A G, G B. On A B describe the square A D C B, and on A G, G B, the squares I A, K B, and through G draw G L parallel to A D or B C, and join G D, H B. Then, because each of the angles A G B, A G I, is a right angle, the two straight lines G B, G I, upon the opposite side G I, make with it at the point G the adjacent angles, equal to two right angles; therefore, B G is in the same straight line with G I: for the same reason G A and G K are in the same straight line; and because the angle D A B is equal to the angle H A G, each of them being a right angle, add to each the angle G A B, and the whole angle D A G is equal to the whole H A B: and because the two sides G A, A D are equal to the two H A, A B, each to each, and the angle D A G equal to the angle H A B; therefore the base G D is equal to the base H B, and the triangle G A D to the angle H A B. Now the parallelogram A L is double of the triangle G A D, because they are upon the same base A D, and between the same parallels A D, G L; and the square I A is double of the triangle H A B, because these also are upon the same base H A, and between the same parallels H A, I B. But the double of equals are equal to one another, therefore the whole square A D C B is equal to the two squares I A, K B, and the square A D C B is described upon the straight line A B, and the squares I A, K B upon A G, G B. Wherefore the square upon the side A B is equal to the squares upon the sides A G, G B.

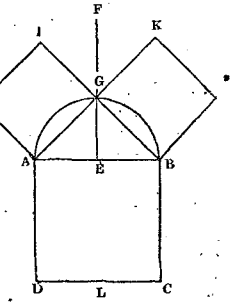


Fig. 1183.

To reduce several Figures to a Rectangle of a given length, as the trapezoid A B C D and the pentagon E F G H I to a rectangle of the width K L: first reduce the figures to triangles of the same height, and twice the breadth K L, as are the two triangles P C Q and R S O: set off the base C Q from K to T, and S O from T to V; at the point T elevate the perpendicular T X, equal in height to P C Q, and draw the right line K X and X V; reduce the triangle X K V to a rectangle, which will be equal to the two figures A B C D and E F G H I.

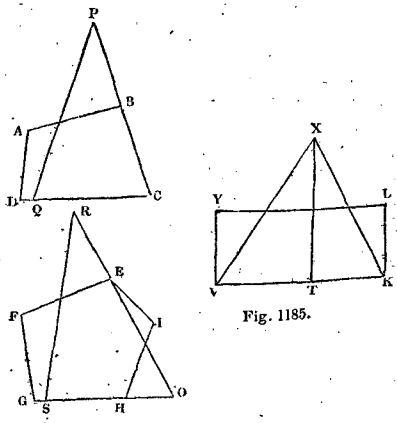


Fig. 1184. Fig. 1185.

To reduce rectilineal Figures to one which shall be similar to a given Figure, as those of the trapezium and pentagon to a figure similar to M*a*b N: reduce the trapezium and pentagon to triangles, and the figure *a*b N M to a triangle M*a* R: reduce the two triangles to the same height, as M*a* R; draw a triangle equal to these three triangles, by setting off the bases from *a* to *b*, *b* to *c*, and *c* to *d*, and elevate the perpendicular *ce* at the point *c*, of the height, of the triangle M*a* R; then draw from the point *e* the lines *ea* and *ed*, which with the right line *ad* will form a triangle equal to the three: then reduce the triangle *eda* to a rectangle *fgda*, and remark where *fg* cuts *ce* in *h*, and prolong *af* and *dg*: take the base *ba*, and set off on *fg*, from *h* to *i*, and draw *ci* until it cuts *dg* prolonged in *k*; draw a line parallel to *fg* through *k*, until it cuts *af* prolonged in *l*; from the point *l* draw *lc*, remark where it cuts *fg* in *m*: draw a perpendicular *nm* to *fg*, through the point *m*, and at *i*, the perpendicular *oip*.

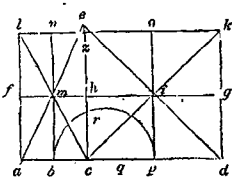


Fig. 1186.

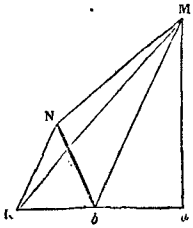


Fig. 1187.

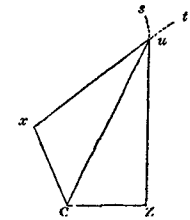


Fig. 1188.

Find a mean proportional between the length *bc* and *cp*, by bisecting *bp* in *q*, and from *q* as a centre, with the radius *qb* describe a semicircle, and remark where it cuts the perpendicular *ce* in *r*; the length *cr* will be a mean proportional between *bc* and *cp*: set off this mean proportional *cr* from *z* to *c*; divide the figure M*ab*N into two triangles by means of the diagonal *b*M, and draw on the line C Z, at the point Z, an angle C Z*s*, equal to *ba* M; and at the point C, an angle C Z*s*, equal to *ab* M, and remark where the two lines C*s* and C*t* intersect at *u*; from this point *u* draw the angle C*ux*, equal to *b*M*n*, and at the point C an angle equal to M*b*N; the figure *u*Z C*z* will be equal to the two triangles, and similar to the figure *ab*N M.

The above principles are drawn from Prop. 1. of Euclid's Sixth Book, wherein he states that triangles and parallelograms of the same altitude are one to another as their bases, and he observes in the cor. attached, "Let their figures be placed so as to have their bases in the same straight line, and having drawn perpendiculars from the vertices of the triangles to the bases, the straight line which joins the vertices is parallel to that in which their bases are, because the perpendiculars are both equal and parallel to one another.

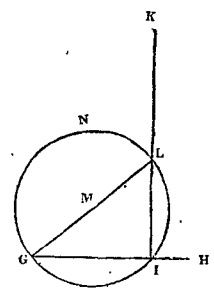


Fig. 1189.

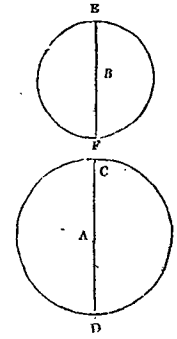


Fig. 1190.

To reduce several Circles to a single one, as the superficies of the two circles A and B to one: draw the diameter C D and E F; draw a line G H, on which set off C D from G to I, and elevate a perpendicular from this point I, on which set off the other diameter E F from I to L: draw G L; bisect it in M: from M as a centre with the radius M L, describe the circle G N L I, which will be equal to the two given circles A and B.

To draw a Square the Double or Quadruple of another.—To double the square A B C D, prolong the side D E toward the place you wish the square extended: from D as a centre, with the radius D E, describe an arc B E, cutting D C prolonged in F: on D F construct a square G H F D, which will be double the square A B C D.

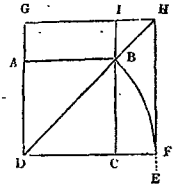


Fig. 1191.

Vitruvius has given us the method practised in his time for doubling the square: that valuable author observes, "If there be an area or field whose form is a square, and it is required to set out another field, whose form is also to be square, but double its area, as this cannot be accomplished by any numbers or multiplication, it may be found exactly by drawing lines for the purpose, and the demonstration is as follows:—A square plot of ground, 10 feet long by 10 feet wide contains 100 feet; if we have to double this, that is, to set out a plot also square, which shall contain 200 feet, we must find the length of a side of this

square, so that its area may be double, that is 200 feet. By numbers this cannot be done, for if the sides are made 14 feet, these multiplied into each other give 196 feet; if 15 feet they give a product of 225 feet. Since, therefore, we cannot find them by the aid of numbers, in the square of 10 feet a diagonal is to be drawn from angle to angle, so that the square may be divided into two equal triangles of 50 feet area each: on this diagonal, another square being described, it will be found that whereas in the first square there were two triangles, each containing 50 feet, so in the larger square formed on the diagonal, there will be four triangles of equal size and number of feet to those in the larger square; in this way, Plato demonstrated the method of doubling the square. Rules for extracting the square root have since been discovered, and we no longer admit it to be impossible to answer this question by figures, for the square root of 200, which is 14·14211356, would be the length of the side of the square that would contain the superficial area of 200 feet.

To construct rectilineal Figures similar and double to given Figures of the same Number of Sides. It is required to draw a rectangle similar to and double the square A B C D: prolong the line D C, and set off the base from C to E, and from E to F: find a mean proportional between E F and E D, by elevating a perpendicular to E F, at the point E, and biseeting D F in H: from H as a centre, with the radius H D, describe the semicircle D I F, cutting E G in I; the right line E I will be the mean proportional required: set off the mean proportional on D C prolonged from D to L, and on this length construct a rectangle similar to A B C D; which is done by forming at the point L an angle D L M, equal to D C B: draw the diagonal D B, until it cuts L M in N; through N draw a line parallel to A B, and remark where the line N O cuts D A; prolong it in P, the figure P N L D will be similar to and double A B C D.

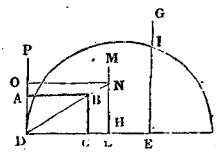


Fig. 1192.

To double, triple, or quadruple the Circle. — To draw a circle, whose superficies shall be double that of B, draw the diameter C D: elevate the perpendicular D E at the point D; on it set off the radius B D from D to E, in order to draw B F, which will serve as a radius to describe from A as a centre, a circle which will be double the given circle B.

If it be required to have the circle tripled: from F elevate the perpendicular F K, on which set off the radius B D from F to E, and draw B K; it will be a radius for describing a circle M N O, which will be triple the given circle B.

If it be required to have the circle quadrupled, elevate the perpendicular L B from the point L, and set off the radius B D upon it: from L to A draw B Q, and it will serve as a radius to describe a circle, which will be the quadruple of the given circle B.

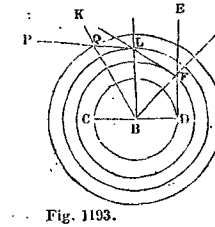


Fig. 1193.

Geodesy is synonymous with land-surveying, and comprehends all those trigonometrical and geometrical operations which more particularly have for their object the determination of the magnitude and figure of the whole or any part of the earth's surface. The 37th prop. of the First Book of Euclid states that triangles upon the same base, and between the same parallels, are equal to one another: upon this proposition, most of the following rules are founded.

To divide triangular Figures into several equal Parts which shall all unite at one Angle. — It is required to divide the triangle A B C into two equal parts both uniting at the angle A: divide the line C B into two equal parts at D, and draw the right line A D; this right line will divide the triangle into two equal parts.

To divide the triangle A B C into two equal parts, uniting in the centre of the side A C: bisect A C in D; draw D B; it will divide A B C into two equal parts.

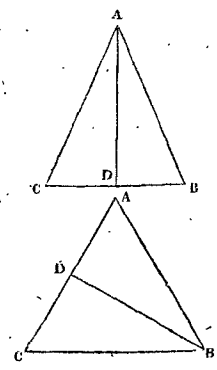


Fig. 1194.

To divide the Isosceles Triangle into three equal parts meeting in the point H on the side E G: divide the side E F opposite the point H, into three equal parts in the points 1, 2, 3; draw H I and also G K parallel to it from the point G, cutting E F in L; from L draw L H to the given point H, from the given point H draw H 2, and from the point G draw G N parallel to H 2, cutting E F in N, from N draw N H: then will the triangle E F G be divided into three equal parts by the lines H I and H N.

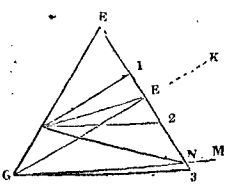


Fig. 1195.

To divide the Triangle E F G into four equal parts meeting at the point H, on the side F G: divide G F into four equal parts in the points 1, 2, 3, 4; from the point E draw the right line E 1; from the point H draw the right line H 1, and through E a line parallel to it, cutting G F in K, and draw H K: set off the line C K on G F from K to L, and draw H L: set off K L from L to M on G F, and draw H M and H F; draw M N parallel to it, cutting E F in O; draw H O: the lines H O, H L, and H K, will divide the triangle E F G into four equal parts.

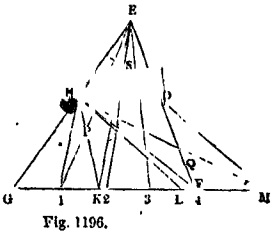


Fig. 1196.

To prove that the triangle E F G is divided into four equal parts, H K G, H L K, H O F L, H E O, it is only requisite to remark that the triangle E F G has its base G F divided into four equal parts by the points I, 2, 3, and 4, and which form the triangles E I G, E 2 I, E 3 2, and E F 3, the heights and bases of which are all equal, and each forms a fourth of the triangle E F G. This must be so, for the triangles H E K and I E K are upon the same base E K, and between the same parallels H I and E K, so that cutting off the common triangle P E K, the two triangles H E P and I K P, which are equal, will remain; if from the triangle E I G we cut off the triangle H E P to take its equal I K P, we shall have the triangle H K G equal to E I G, and consequently to a quarter of the triangle E F G.

It is to be observed that the three triangles H K G, H L K, and H M L, being of the same height, and having their bases G K, K L, and L M equal, are equal each to each; and as the triangle H K G has been proved to be the fourth of the great triangle E F G, the two other triangles H L K and H M L are also each the fourth of this great triangle: but as the triangle H M L comes out of the triangle E F G, that it may be comprised within it, the right line H F, and its parallel M N are drawn, which form the triangles H O M and F O M, which being on the same base O M, and between the same parallels H F and O M, are equal, so that in cutting off from these two equal triangles the common triangle Q O M there will remain the two triangles H O Q and F M Q, which are equal; if from the triangle H M L we cut off the triangle F M Q, to take its equal H O Q, we have the figure H O F L equal to the triangle H M L, and dividing into four the great triangle E F G; and as we have proved that the three figures H K G, H L K, and H O F L, are each a quarter, the remainder H E O is the fourth quarter.

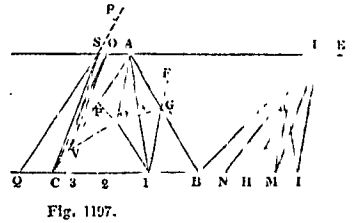


Fig. 1197.

To divide the Triangle A B C into three equal parts uniting at the point D: draw through the point A a line A F parallel to the line B C: divide C B into three equal parts in the points 1, 2, 3; draw A D, and through 1 a line 1 F, parallel to A D, cutting A B in G: from D draw D G and D 1: set off B 1 from B to H, and D G from H to I, and on this line I H draw the triangle K I H equal and similar to A G D: elevate the triangle K I H to the height of A B C, and you will have L M H: set off H M from B to N, and H N from A to C, and draw O C: take the shortest distance from D to A C, as D P, to draw a line parallel to A C at the distance, as Q R, cutting A E in S; from which point S, draw S C, and through C another parallel to it, as C T, cutting A C in V; draw V D: the lines 1 D, D G, and D V will divide the triangle A B C into three equal parts uniting at the point D.

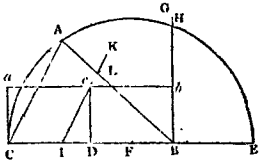


Fig. 1198.

To divide Triangles into equal Parts by lines parallel to their sides: as to divide A B C into two equal parts parallel to A C; prolong one side C B, and bisect it in D; set off B D from B to E: find a mean proportional between C B and B E, as B H: set off B H on B C from B to I: through I draw I K parallel to A C: the line I K will divide the triangle A B C into two equal parts.

To divide Figures of four Sides into several equal parts, as the square A B C D into three equal parts, all uniting at A: draw the diagonal B D, and divide it into three equal parts, in 1, 2, 3: from A draw the line A 1, A 2: draw A C and 1 E and 2 F parallel to A C: then draw A E and A F; these two lines will divide the square A B C D into three equal parts uniting in the angle A.

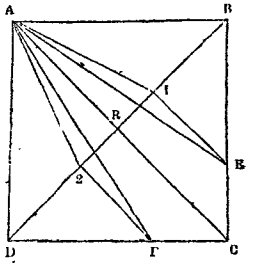


Fig. 1199.

To divide Figures of four Sides into several equal parts uniting at a point on one side; as to divide the four-sided figure A B C D into two equal parts uniting at E: reduce the quadrilateral A B C D to a triangle, A F D, and bisect the line D F in G: draw G E, and through A a line parallel thereto, H A; draw H E, and it will divide the four-sided figure into two equal parts.

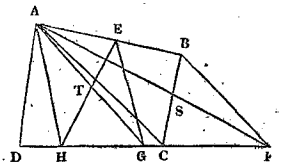


Fig. 1200.

To divide Figures of four Sides into several equal parts uniting at a point in their superficies: as to divide A B C D into two equal parts, uniting at the point E: divide the trapezoid A B C D into two equal parts, uniting by a line, F G, passing through the point E; reduce the trapezoid A B C D, to a triangle A H D, and F B C G to a triangle F I G: draw A K parallel to D H: elevate the triangle F I G to the same height as A H D, and you will have the triangle L M G: bisect the base D H in N, and draw A N, forming the two equal triangles A H N and A N D: set the base M G of the triangle L M G on the line H N of the triangle A H N, and remark if these two lines are equal: but since the base M G is shorter by the distance O N, set off this distance O N from G to P, and draw L P, forming the triangle L G P: then remarking the figure F B C Q only contains I M G, or its equal, A H O, you must add to this figure the triangle A O N or L G P, lowering the height to E on the side D H, as is the triangle E G Q, which will give you the irregular pentagon F B C Q E for one half, and A E F Q D for the other half of the trapezoid A B C D.

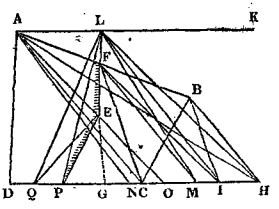


Fig. 1201.

To divide Figures of four Sides into several equal parts by lines parallel to one of their sides: as to divide the trapezoid H I K L into two equal parts by a line parallel to H L: reduce the trapezoid H I K L to a triangle H M L: bisect its base L M in N: prolong L K and H I till it cuts L K prolonged in O: find a mean proportional between O L and O N, as P Q, which set off from O to R, and draw R S parallel to H L; it will divide the trapezoid into two equal parts.

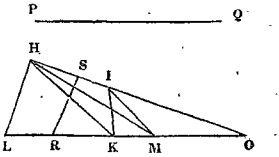


Fig. 1202.

To divide Pentagonal Figures into several equal parts abutting at one angle: as the regular pentagon A B C D E into two equal parts abutting on the angle A. Reduce the pentagon A B C D E to a triangle, A F G: bisect the base G F in I, and draw A I, it will divide the pentagon A B C D E into two equal parts.

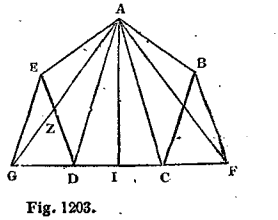


Fig. 1203.

To divide Pentagons into several equal parts, abutting at a given point on their sides; as to divide the irregular pentagon A B C D E into two equal parts uniting at the point F. Reduce the pentagon to a triangle, A G E: bisect the base E G in H, and draw A H forming the triangle A H E: half the triangle A G E, or the pentagon A B C D E: then lower the triangle A H E to F, as F I E: draw F D, and through I its parallel I K, and draw F K, which will divide the pentagon into two equal parts.

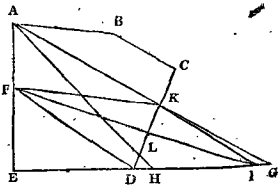


Fig. 1204.

To divide Pentagonal Figures into several equal parts uniting at a point in their superficies: as to divide the irregular pentagon A B C D E into two equal parts, abutting at the point F. Divide the pentagon into two equal parts by a line passing through the given point, as G H; then reduce the pentagon to a triangle, A I E, and the figure G B C D H to a triangle G K H, which you must elevate as high as A I E, as is done in the triangle L M H: divide the base E I into two equal parts in N, and draw N A, which will form the triangle A I N: set the base I N on the base M H; it will be greater by the distance H O: draw O L forming the triangle L M O: lower the triangle L H O to the point F, as F H P, which will give you G B C D P F for half the pentagon A B C D E.

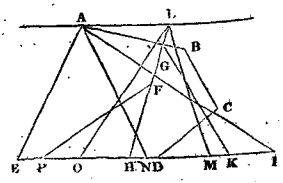


Fig. 1205.

To divide Pentagons by lines parallel to their sides into several equal parts, as the irregular pentagon, A B C D E, into two equal parts, by a line parallel to E D: reduce the pentagon to a triangle, A F G; bisect its base G F in H, and draw A H: reduce the trapezoid, A H D E, to a triangle, E I D; prolong the base I D, and the side A E, until they intersect in K: find a mean proportional, L M, between K I and K D; set off the mean proportional on K I, from K to N; through the point N draw a line, N O, parallel to E D, and it will divide the irregular pentagon into two equal parts.

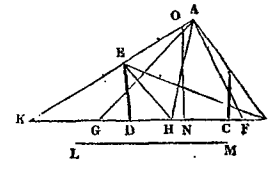


Fig. 1206.

To divide Hexagons into several equal parts, uniting at one of their angles: first reduce the irregular hexagon, as A B C D E F, to a pentagon: then to a trapezoid, and lastly to a triangle. To reduce the hexagon, A B C D E F, to a pentagon, prolong the side D C to I: draw A C, and from B a line parallel thereto B K, and divide A K, which will reduce the hexagon to the pentagon, A K D E F. To reduce this to a trapezoid, prolong the side E D, and draw A D, and from K draw K G parallel to A D; draw A G, which will reduce the pentagon to the trapezoid, A G E F: reduce the trapezoid to a triangle by drawing from A the right line A E, and through F its parallel F H, and draw A H, which will form the triangle A G H, equal to the trapezoid A G E F: then divide the base, HG, into two equal parts in L, and draw A L, which will divide the hexagon into two equal parts.

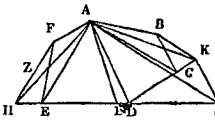


Fig. 1207.

To prove that the irregular hexagon ABCDEF is divided into two equal parts ABCDL and ALEF, which join at the point A.

The angle A G F is equal to the irregular hexagon A B C D E F, and the triangle A G H has its base equally divided at the point L, so that the two triangles A G L and A L H, having the same height and base, are equal; and as they are the moieties of the triangle A G H, they are also the moieties of the hexagon A B C D E F, which is equal to the triangle A G H.

The two triangles A E F and A E H being upon the same base A E, and between the same parallels F H and A E, they are equal: A E F and A E H are also equal, as are F A Z and H E Z.

If from the triangle A L H, which is the half of the hexagon A B C D E F, we cut off the triangle H E Z, and take its equal F A Z, we shall have the figure A L E F equal to the triangle A L H, and also the moiety of the figure A B C D E F.

To divide Multilateral Figures, having re-entering angles, into several equal parts, uniting at one angle, as to divide the irregular heptagon, A B C D E F G, into six equal parts, uniting at the angle B: reduce the irregular heptagon to a triangle B N M, draw B D in C N; divide M N into six equal parts, in the points 1, 2, 3, 4, 5, 6, and draw right lines to them from B; draw E B, and through 2 a line 2 O, parallel to E B, and draw O B. Reduce the irregular pentagon A B O F G to a trapezoid, B O F P, by prolonging F G, and from G draw the right line G B, and from A, A P, parallel to B G, and draw P B: set off the base of one of the small triangles, as 4 3, and F G, from P to Q. Take also the length of its side 4 B, and describe from the point P an arc R; take the length of its other side, 3 B, and from the point A describe the second arc S, cutting the first in T: then draw the two lines Q T and P T, which will form the triangle Q P T equal to B 4 3. Through B draw a line parallel to F Q, as B V, cutting P T in X: then lower the triangle T P Q to X, and you will have X P Y equal to T P Q. If, then, you set off the base Y P from P to Z, and draw Z B, you will have the two triangles B Z P and X P Y equal to each other. The triangles B G A and B G P being equal, if to the triangle B Z G you add the triangle B G P, you will have the triangle B Z P; and if to the triangle B Z G you add B G A, you will have the trapezoid B Z G A equal to B Z P, and

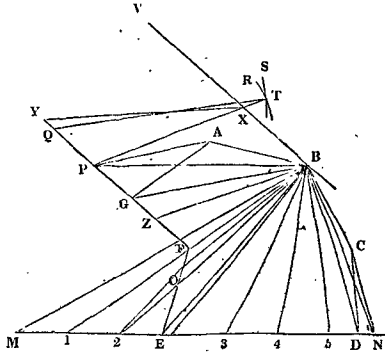


Fig. 1208.

consequently a sixth of the heptagon, A B C D E F G: there will remain the trapezoid B O F Z for the last sixth. Thus the irregular heptagon will be divided into six equal parts by the lines B, Z, O, 3, 4, 5.

To divide Figures of unequal Dimensions by similar Lines, as to divide the figure A B C D into three parts similar to three divisions on the plan E F G H: measure the length E I of the plan, E F G H, with the scale K, as 45: measure likewise on the figure A B C D 45, from A to L: then take with a protractor the angle E I M, 105°, and from the angle A L N also 105°, on the side A B, at the point L. Measure the length F O, 40°, with the scale K, and set off 40° from B to P; at the point P draw the angle B P Q equal to F O M: then, having found that the distance G R is 70 parts, set off the same number from C to S. At the point S draw the angle C S T equal to G R M: the lines L, N, P, Q and S, T, intersecting at V, will divide the figure A B C D similarly to E F H G.

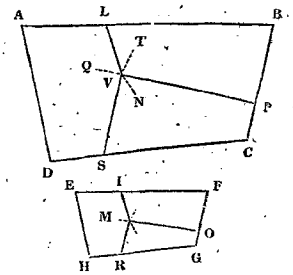


Fig. 1209.

Mensuration of Solids.—Determine the value of the spaces included by contiguous surfaces, and the sum of the measure of those including surfaces is the whole surface or superficies of the body; the rules for performing such operations we have already described. The measure of a solid is called its solidity, capacity, or content, and is usually measured by cubes, whose sides are inches, feet, or yards: hence the solidity of a body is said to be so many cubic inches, feet, yards, &c., as will fill its capacity or space, or another of an equal magnitude.

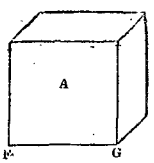


Fig. 1210.

The cube A may be supposed to contain a solid foot, consequently 1728 cubic inches; for if the area of its base were divided into square inches, it would contain 144, and as the cube is 12 inches in height, it would permit of 12 layers of cubical inches being piled up to complete the figure, or 144 cubes $\times 12 = 1728$: consequently, to find the solid content of a cube, we only have to multiply the area of its base by its height.

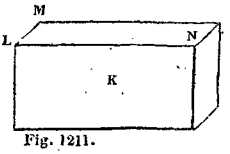


Fig. 1211.

Of a Parallelopipedon.—Multiply the area of one end by the length, and the product is the solid content.

Inclined Parallelopipedons are cubed in a similar manner. The solid content of a rectangular parallelopipedon is said to be equal to the product of its three dimensions, that is, as A B × A C × A D, when A B, A C, A D, are the three edges: this expression being interpreted in the same sense with the product of the two dimensions or sides, which is said to constitute the area of a rectangle, viz. that the number of cubical units in the parallelopiped is equal to the product of the numbers which denote how often the corresponding linear unit is contained in the three edges: it is on this account said that the solid content of a rectangular parallelopiped is equal to the product of its base and altitude. The cube is considered a unit in the mensuration of all other solids, their content being the same with the content of rectangular parallelopipeds equal to them.

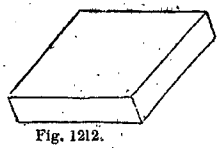


Fig. 1212.

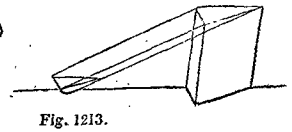


Fig. 1213.

Prisms in general have their solid content found by multiplying the area of their base by their height.

To find the solid content of an irregular solid whose sides are parallel, we must first measure it in detail, find the content of the several parts, and add them together: the present example might be taken as three parallelopipedons; or the solid content of the parts cut out might be ascertained, which, deducted from the solid content obtained by multiplying the area of its base by its height, would give the content of the irregular solid. As all prisms and cylinders are equal to parallelopipedons of equal bases and altitudes, it is only necessary to multiply the base or end by the height to obtain the solid content.

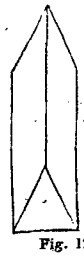


Fig. 1214.

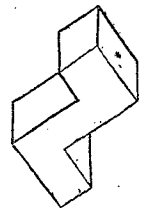


Fig. 1215.

Pyramid, or Cones: multiply the area of their base by one third of their height for the solid content.

To find the solidity of the frustum of a cone or pyramid, add into one sum the area of the two ends, and the mean proportional between them, and take two-thirds of the sum for a mean area, which being multiplied by the perpendicular height will give its content.

Suppose we call a^2 the area of the base of the frustum of a pyramid, b^2 the area of the top, h the perpendicular height, and c the height of the pyramid when the frustum is made complete.

Then $c+h$ = the height of the whole pyramid.

Then $\frac{1}{3}a^2(c+h)$ is the content of the whole pyramid, and $\frac{1}{3}b^2c$ the content of the top part: therefore the difference $\frac{1}{3}a^2(c+h)-\frac{1}{3}b^2c$ is the content of the frustum.

But the quantity c being no dimension of the frustum, it must be expelled from this formula, by substituting its value in the following manner,

$$a^2 : b^2 :: (c+h)^2 : c^2, \text{ or } a : b :: c+h : c;$$

$$\text{hence, } a-b : b :: h : c, \text{ and } a-b : a :: h : c+h;$$

$$\text{hence therefore, } c=\frac{bh}{a-b}, \text{ and } c+h=\frac{ah}{a-b};$$

then these values of c and $c+h$ being substituted for them in the expression for the content of the frustum gives that content $=\frac{1}{3}a^2\times\frac{ah}{a-b}-\frac{1}{3}b^2\times\frac{bh}{a-b}=\frac{1}{3}h\times\frac{a^3-b^3}{a-b}=\frac{1}{3}h\times(a^2+ab+b^2)$, which is the rule above given, ab being the mean between a^2 and b^2.

Tetraedron.—Multiply the area of the base by one-third of the perpendicular height for its solidity. Required the superficies and solidity of the tetraedron, whose linear edge is 3 inches.

$$1{\cdot}73205\times3^2=15{\cdot}588 \text{ for its superficies,}$$
$$0{\cdot}11785\times3^2=3{\cdot}18195 \text{ for its solidity.}$$

Hexaedron is the same thing as the cube, already described.

Octaedron.—Multiply the square of its side by the diagonal, and one third of the product will give the solid content.

Required the superficies and solidity of an octaedron, A, the linear sides of which at B E C is each 2 inches: taking from the table

$$3{\cdot}46410\times2^2=13{\cdot}85640 \text{ for the superficial content,}$$
$$0{\cdot}47140\times2^2=3{\cdot}77120 \text{ for its solidity.}$$

Dodecaedron.—Multiply the content of one of its pyramids, E, by 12, because the figure is composed of twelve equal pyramids having a regular pentagon for the base, their summits being the centre of the dodecaedron.

Required the superficies and solid content of a dodecaedron, whose linear edges are 2 inches.

$$20{\cdot}64573\times2^2=82{\cdot}58292 \text{ for the superficies,}$$
$$7{\cdot}66312\times2^2=61{\cdot}30466 \text{ for its solidity.}$$

Icosaedron.—Multiply the content of one of its pyramids, N, by 20, because it contains twenty equal pyramids having equilateral triangles for bases, and their summits in the centre of the body.

Required the superficies and solid content of the icosaedron N.

$$8{\cdot}66025\times2^2=34{\cdot}64100 \text{ for the superficies,}$$
$$2{\cdot}18169\times2^2=17{\cdot}43352 \text{ for the solidity.}$$

The side of any of the five Platonic bodies being given, to find the diameter of a sphere that may either be inscribed in that body or circumscribed about it, or that is equal to it: As the respective number in the following table, under the title inscribed, circumscribed or equal is to 1, so is the side of the given Platonic body to the diameter of its inscribed, circumscribed, or equal sphere.

The side of any one of the five Platonic bodies being given, to find the side of the other four bodies that may be equal in solidity to that of the given body: As the number under the title equal, in the third column of the second table, which stands against the given Platonic body, is to the number under the same title against the body whose side is sought, so is the side of the given Platonic body to the side of the body sought.

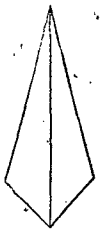


Fig. 1216.

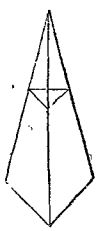


Fig. 1217.

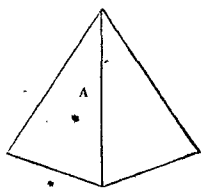


Fig. 1218.

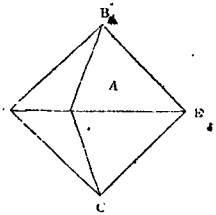


Fig. 1219.

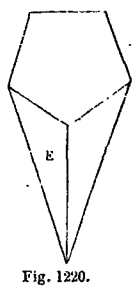


Fig. 1220.

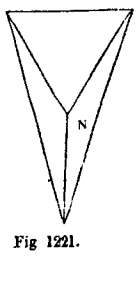


Fig 1221.

To find either the Surface or solid Content of any of the regular Bodies, multiply the tabular area, taken from the following table, by the square of the linear edge of the solid, for the superficial content; and for the solid content, multiply the tabular solidity by the cube of the linear edge.

Number of Sides.	Name.	Surface.	Solidity.
4	Tetraedron - - -	1·7320508	0·1178513
6	Hexaedron - - -	6·0000000	1·0000000
8	Octaedron - - -	3·4641016	0·4714045
12	Dodecaedron - -	20·6457288	7·6631189
20	Icosaedron - - -	8·6602540	2·1816950

The diameter of a sphere being given, to find the side of any of the Platonic bodies that may be either inscribed on the sphere, or circumscribed about the sphere, or that is equal to the sphere.

Multiply the given diameter of the sphere by the proper or corresponding number in the following table, and the product will be the side of the Platonic body required:—

The diameter of a sphere being 1, the side of a	That may be inscribed in the sphere is,	That may be circumscribed about the sphere is,	That equal to the sphere is,
Tetraedron - - -	0·816497	2·44948	1·64417
Hexaedron - - -	0·577350	1·00000	0·88610
Octaedron - - -	0·707107	1·22474	1·03576
Dodecaedron - - -	0·525731	0·66158	0·62153
Icosaedron - - -	0·356822	0·44903	0·40883

To find the Solid Content of a Sphere.—Multiply the cube of the diameter by ·5236, and the product will be the solidity.

Or we may put d = the diameter, c = the circumference, and s = the surface of the sphere or its circumscribing cylinder; also $a = 3{\cdot}1416$, then $\frac{1}{4}s$ = the base of the cylinder, or one great circle of the sphere, and d is the height of the cylinder; therefore $\frac{1}{4}ds$ is the content of the cylinder: but $\frac{2}{3}$ of the cylinder is the sphere; that is $\frac{2}{3}$ of $\frac{1}{4}ds$, or $\frac{1}{6}ds$ is the sphere.

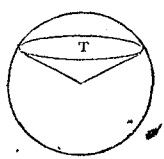


Fig. 1222.

Again, because the surface $s = ad^2$, therefore $\frac{1}{6}ds = \frac{1}{6}ad^2 = 5236\,d^3$ the content; also d being $= c \div a$, therefore $\frac{1}{6}ad^3 = \frac{1}{6}c^3 \div a^2 = {\cdot}01688$. Then if we cube the diameter of a globe, and multiply it by ·5236, or cube the circumference and multiply it by ·01688, we shall obtain the solid content.

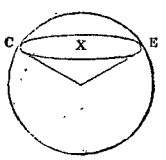


Fig. 1223.

To find the Solidity of a spherical Segment, or Plano-convex Portion of a Sphere.—To three times the square of the radius of the base or flat side, add the square of the versed sine or height; then multiply the sum by the height, and the product so obtained by ·5236 for the solid content; or, from three times the diameter of the sphere take double the height of the segment; then multiply the remainder by the square of the height, and the product by the decimal ·5236 for the content.

To find the Content of a solid Ellipse or Spheroid.—Multiply the square of the transverse by the square of the conjugate diameter, and the product by ·5236.

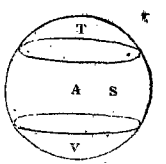
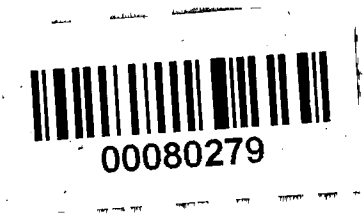


Fig. 1224.

To find the Solidity of a Parabolic Conoid.—Multiply the square of the diameter of the base by the height or length of the axis, and the product by ·3927: two such solids united at the base form a parabolic spindle.

To find the Content of a cylindrical Ring.—Add to the diameter of the cylinder of which the ring is formed the extent of the inner diameter of the ring; then multiply the sum by the square of the thickness on the diameter of the ring, and the product by 2·4674, which is one fourth of the square of 3·1416, and it will give the solidity.

To find the convex Surface of a Sphere.—Multiply the diameter of the sphere by its circumference; or multiply 3·1416 by the square of the diameter, and the product will be the convex surface required.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